METALLURGIA

THE BRITISH JOURNAL OF METALS

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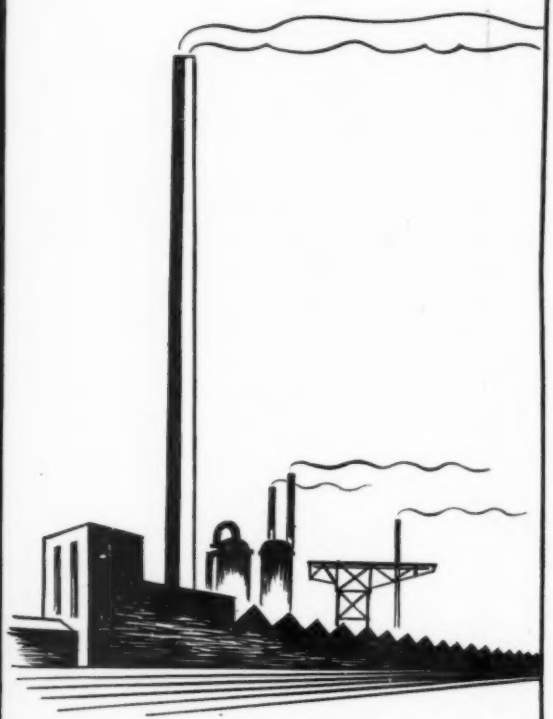


FOR BRITISH INDUSTRY

IMPERIAL SMELTING CORPORATION (SALES) LIMITED · 37 DOVER STREET · LONDON · W.1

METALLURGIA

THE BRITISH JOURNAL OF METALS

INCORPORATING THE "METALLURGICAL ENGINEER"

AUGUST, 1952 Vol. XLVI No. 274

Steel Control Plan

IN line with the King's Speech at the opening of the present Parliament, the Government is proposing to introduce legislation to provide for the reorganisation of the iron and steel industry under free enterprise with an adequate measure of public supervision. A bill to give effect to this policy is due to be presented to the House of Commons early in the next Session, and in the meantime the Government's proposals have been issued as a White Paper.

The most important aspects of the matter as regards the future progress and well-being of the industry are those contained in Section II which deals with the extent of public supervision. In framing these proposals, the Government have had regard to the earlier arrangements for supervision, first by the Import Duties Advisory Committee from 1932 to 1939, then by the Iron and Steel Control during the war, and later by the Iron and Steel Board set up in 1946.

The scope of the Board will be such that all the main processes making up the iron and steel industry will come within its purview, so that the whole industry will again come under the supervision of one authority, without regard to the present distinction between nationalised and non-nationalised sectors. The Board will not, however, be concerned with the extensive engineering activities carried on by steel companies.

When the proposed duties and powers of the Board are examined they certainly appear to meet the situation as far as those people are concerned who wish to ensure that the industry is carried on in an efficient manner, and that adequate steps are taken to ensure that, in so far as is humanly possible, the nation shall never be let down by the industry failing to meet its needs, but who, at the same time, do not wish to see capital and labour diverted from other essential fields of activity because somebody has a "bee in his bonnet" concerning the steelmaking capacity which should be available. Apart from its general duty of supervising the industry with a view to promoting the efficient economic and adequate supply of steel, the Board will be required to keep under review: (*a*) development of production capacity; (*b*) prices; (*c*) raw material supplies; (*d*) research and technical training; (*e*) arrangements for joint consultation between management and employees on matters of mutual interest other than wages and conditions of service; and (*f*) arrangements for the safety, health and welfare of employees.

Obviously, one of the most important items in the list is the first—the development of production capacity—which necessitates a good deal of foresight, and entails the provision of large capital sums. It will be the responsibility of the Board to supervise capital development and in the course of performing that function it will have to discuss with the companies their plans for the future, in order to ensure that individual schemes are consistent with the proper development of the industry as a whole, and that any additional capacity or improved facilities required will be provided. No doubt most of the foundation work in this direction will be carried out as at present by the Iron and Steel Federation which performs a similar function within the industry. A company putting forward a major scheme which, in the opinion of the Board, is likely to prejudice the efficient and economical development of the industry as a whole, may be restrained from putting the scheme into effect, with a right of appeal to the Minister of Supply.

On the other hand, it may at times be desirable, on the grounds of general national interest, to carry out schemes of capital development which on commercial grounds no company is able to undertake. In such cases, the Minister of Supply is to be given powers to arrange, after consultation with the Board, for the provision and operation of the additional works or other facilities required. The reason for giving these positive powers to the Minister rather than to the Board, is that if the Board are to preserve impartiality in the performance of their duty of supervising the industry as a whole, they must remain free from responsibilities of ownership or management in respect of particular concerns.

No less important, in view of the effect on the national economy, is the proposal to give the Board power to fix maximum prices for sales in the United Kingdom. It is further intended that the Government should have in reserve a power to intervene in the fixing of maximum iron and steel prices should the public interest so require. An important clause in the Bill will provide that all producers of iron and steel shall be deemed to have entered into a contractual obligation with the Board to observe their decisions in relation to development and prices. The Board's decisions will thus be enforceable by civil proceedings for an injunction.

It will be the duty of the Board to ensure that the industry has made satisfactory and adequate arrangements for the importation of the raw materials it requires and to take steps to secure such imports should the case be otherwise. In the same way, the Board may also, if necessary, arrange for the import of iron or steel, in finished or semi-finished form. With the approval of the Minister of Supply, the Board may sell such imports below cost, to avoid serious price discrepancies, the loss being recovered from appropriate sectors of industry, as is done at present.

With the powers outlined above, there should be no difficulty in the Iron and Steel Board exercising such control over the industry as would set at rest the doubts of those who see danger in the existence of an absolutely free and unfettered iron and steel industry. It will not, of course, satisfy the left wing extremists, but it is to be hoped that common sense and considered judgment will be featured in the Parliamentary discussions on the Bill, rather than party bias, whether it be of the right or of the left.

The Institute of Welding

New President Installed

Mr. A. Robert Jenkins, J.P., A.I.Mech.E., deputy Managing Director of Robert Jenkins & Co., Ltd., of Rotherham, was installed as President of the Institute of Welding for 1952/53 at the annual general meeting of the Institute on July 22nd at the Institution of Civil Engineers.

Mr. Jenkins, who was educated as a mechanical engineer at Sheffield University and as a pupil apprentice with W. H. Allen & Sons, Ltd., of Bedford, entered the family business at Rotherham in 1931 as Plant Maintenance Engineer. Shortly afterwards he took charge of the Works Progress Department, became Works Manager and a director of the company in 1934 and in 1946, as Works Director, became responsible for the whole of the production and technical side of a works now producing about a thousand tons of fabricated products a month.

Mr. Jenkins has travelled widely, visiting factories in Sweden, Germany and the U.S.A. and was a member of the Specialist Productivity Team on Welding, which visited the U.S.A. in 1950. He serves on the Council of the British Welding Research Association, the Rotherham and District Employment Committee and the Management Committee of the Sheffield Engineering Employers' Association, and has been President of the Rotherham Chamber of Commerce since 1950. He is a founder-member of the Sheffield Branch of the Institute of Welding and President of the Branch.

The new Vice-President of the Institute is Mr. H. B. Fergusson, M.I.N.A., M.I.Mech.E., M.E.I. Canada, who for 15 years has been a Director of G. A. Harvey & Co. (London), Ltd. Mr. Fergusson was educated as a mining engineer in Freiberg, Germany and later articled to his father, a member of the Institution of Civil Engineers. He has had a distinguished career in railway construction and other engineering projects.

Institute of Metal Finishing

Medals and Awards

The Council of the Institute of Metal Finishing has approved the establishment of the following Medals and Awards. These have been made possible through the generosity and co-operation of three of the Corporate Members of the Institute.

Hothersall Memorial Medal and Lecture. The Mond Nickel Co., Ltd. have very kindly endowed the annual award of a palladium medal (with which will be associated a sum of £50) for an initial period of seven years. The award will be presented to a person of eminence selected by the Council of the Institute who will be invited to deliver a lecture in memory of the late Mr. A. W. Hothersall to be known as the Hothersall Memorial Lecture.

Johnson Matthey Silver Medal. Through the generosity of Johnson Matthey & Co., Ltd., a Silver Medal will be awarded annually, or at such times as may be decided by the Council, for the best paper presented to the Institute on the deposition of precious metals.

Westinghouse Brake and Signal Co., Ltd. Prize. Finally, the Westinghouse Brake and Signal Co., Ltd. have generously endowed an award for the publication appearing in the Journal of the Institute which, in the opinion of the Publications Committee, shows the most valuable advance in the science or practice of electrochemistry in general and electrodeposition in particular. The Award will amount to £25 annually and will consist largely of a selection of books. There is no restriction respecting subject matter within the limits mentioned above; neither is there any restriction respecting age or nationality of candidates for the Award. The Award is to be endowed for a period of seven years in the first place and is then to be subject to renewal or revision.

In the case of the Johnson Matthey Silver Medal and the Westinghouse Brake and Signal Co., Ltd. Prize, both members and non-members of the Institute are equally eligible, and papers should be submitted direct to the offices of the Institute at 32, Great Ormond Street, London, W.C.1.

New Chairman for B.S.I.

At the annual general meeting of the British Standards Institution, held at 24, Victoria Street, S.W.1, on Wednesday, July 23rd, it was announced that the General Council had elected Mr. John Ryan, C.B.E., M.C., as its Chairman to succeed Sir Roger Duncalfe, who had completed his three years term of office. In the course of the meeting, the Rt. Hon. Viscount Waverley, P.C., G.C.B., G.C.S.I., G.C.I.E., F.R.S., was re-elected President of the Institution for the third year. Sir Roger Duncalfe was elected Vice-President. Sir Roger's term as Chairman had coincided with B.S.I.'s period of most rapid growth, and his acceptance of the Vice-Presidency reflects his continuing and active interest in the Institution's work.

As Chairman of British Glues and Chemicals, Ltd., Sir Roger Duncalfe is widely known in industry. He is past Chairman and Past President and now a Vice-President of the Association of British Chemical Manufacturers, and a Vice-President of the Federation of British Industries. He had previously been Chairman of the B.S.I. Adhesives Industry Standards Committee, and of the Finance Committee.

The new Chairman, Mr. John Ryan, is Vice-Chairman of the Metal Box Co., Ltd., and he has for many years played a leading part in the standardization policies implemented through B.S.I., by the packaging industry. He was appointed Chairman of the Packaging Standards Committee on its formation in 1941, and was intimately concerned with the development of the wartime Packaging Code. This not only resulted in dramatic economies in packaging materials and labour during the war, but through the progressive accumulation of technical data has since made available to British industries the most economical and efficient packing techniques particularly in the export field.

In 1948, Mr. Ryan followed Sir Roger Duncalfe as Chairman of the B.S.I. Finance Committee, and for the past four years he has served on the General Council and its Executive Committee. He occupies many other important offices both in industry and in public service.

Widely known as an expert in company finance and administration, Mr. Ryan is a member of the council and a fellow of the Royal Statistical Society, and holds senior offices in many trade organisations and the British Institute of Management. His great experience and wise judgment will clearly be of great value to B.S.I., since by long-established tradition the Chairman of the General Council works in close collaboration with the chief executives of the Institution in the conduct of its affairs.

Factors Influencing Pack Carburising

By E. Mitchell, A.I.M., A.C.T.

Heat Treatment Development Engineer, Joseph Lucas Limited

A series of tests to establish the effect of various factors, including temperature and amount and type of energiser, on the nature of the case obtained with both plain carbon and alloy case-hardening steels, is described. The effect of dilution of the carburising compound is discussed, and a suggestion made for a compound which will prevent the formation of the heavy carbide networks normally associated with heavily alloyed case-hardening steels. Other factors which normally influence the commercial pack carburising process are examined and discussed.

ALTHOUGH gas carburising is, to a large extent, likely to replace pack carburising in large heat-treatment departments, there will still remain a large number of components which, by virtue of their shape or quantities required, will still be carburised most economically by the pack method. The series of tests described in this article were made with the object of establishing the influence of various factors on the nature of the case obtained with both plain carbon and alloy carburising steels.

It is believed that most users of the pack carburising method experience difficulty in obtaining a case substantially free from heavy carbide networks when deep carburising the highly alloyed steels, especially the chromium-bearing group. Additionally, nearly all users of the pack method meet with difficulties when faced with the production of a light case of the order of 0·010 – 0·015 in. if close limits are placed on depth of penetration.

Present Day Practice

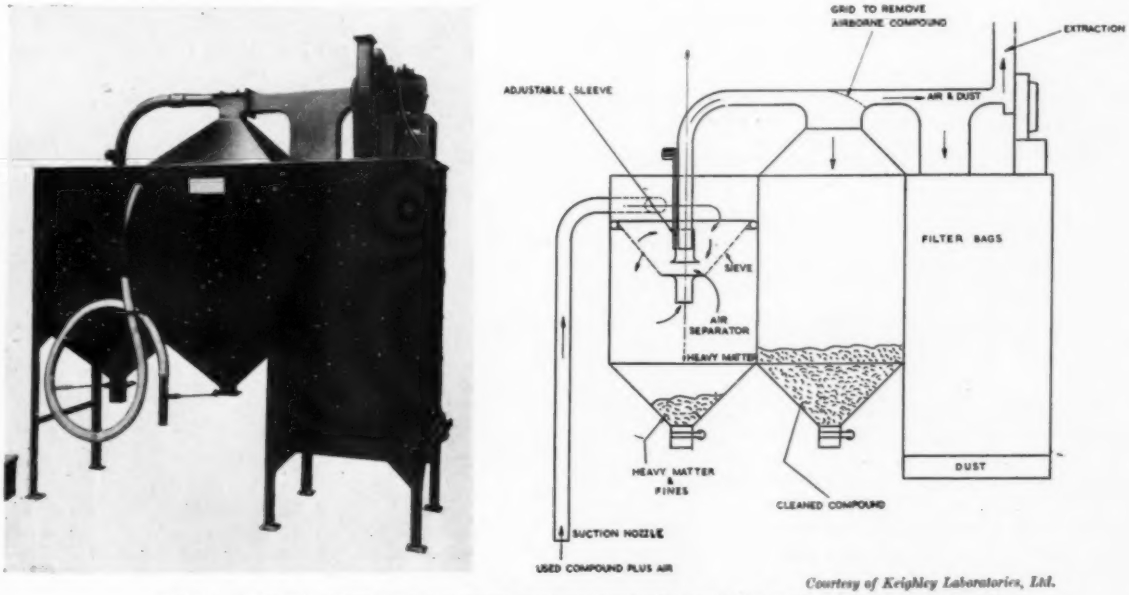
Carburising Media.—For certain special applications, a paste-type carburising medium is used but, in general, the use of charcoal, or coke plus charcoal, with the addition of appropriate quantities of energiser is the rule.

TABLE I.—DETAILS OF CARBURISING COMPOUNDS USED

Compound No.	Type	Energiser
1	Charcoal base. Retort distilled British oak.	2½% barium carbonate (molasses solution bond).
2	As No. 1	5% barium carbonate (molasses solution bond).
3	As No. 1	10% barium carbonate (molasses solution bond).
4	As No. 1	15% barium carbonate (molasses solution bond).
5	As No. 1	3% sodium carbonate.
6	As No. 1	5% sodium carbonate.
7	Coke-charcoal base	8% barium carbonate.
8	Hardwood charcoal	No energiser.
9	Dust obtained after passing No. 6 through ¼ in. mesh.	22% sodium carbonate.

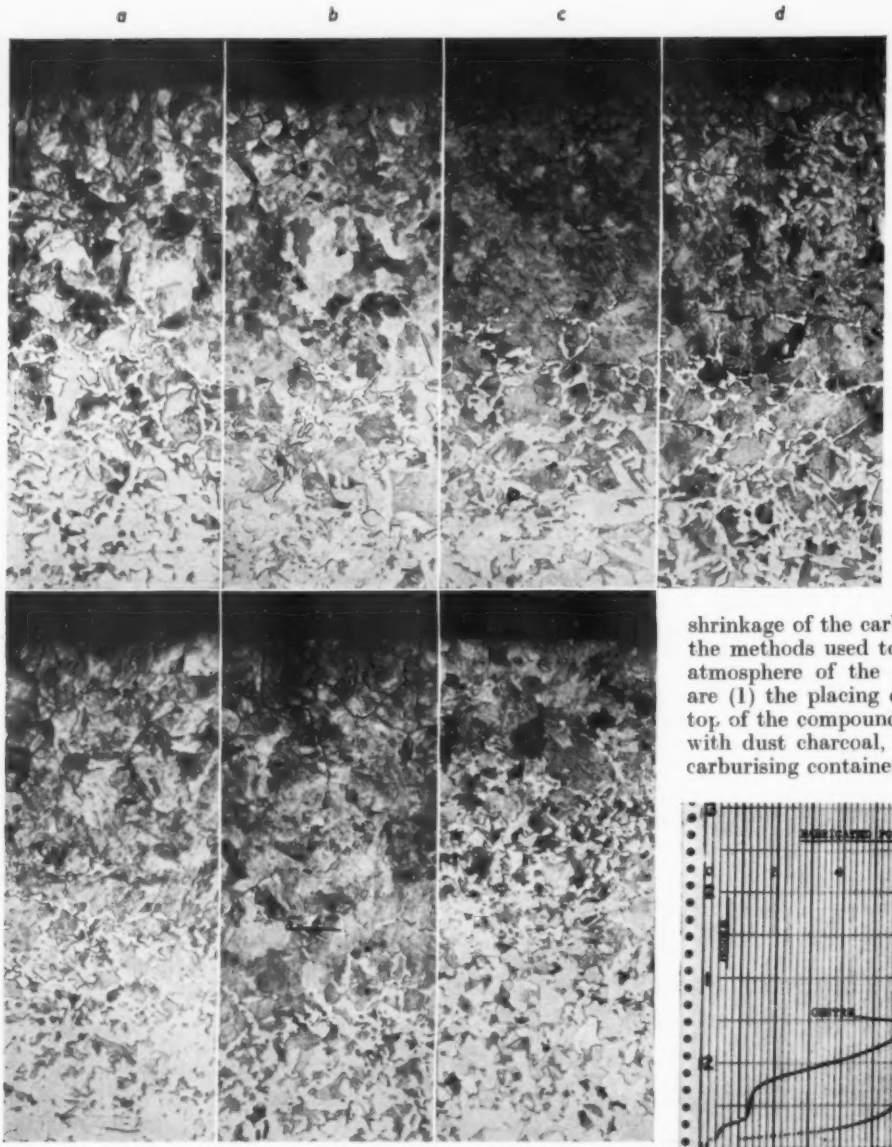
TABLE II.—RESULTS OF TESTS ON COMPOUND SAMPLES

Compound No.	Retained on ¼ in. mesh %	Retained on 30 mesh/in. %	Dust %
3	94	0·7	4·9
6	96	2·5	1·5
7	80	17·5	2·2



Courtesy of Keighley Laboratories, Ltd.

Fig. 1.—The K.L. Controller, a vacuum-type screening unit for carburising compound.



(*a*) 2½% $BaCO_3$
(*b*) 15% $BaCO_3$.
(*c*) 5% Na_2CO_3.
(*d*) Coke base.
(*e*) Dust 22% Na_2CO_3.
(*f*) ⅔ 5% Na_2CO_3 compound + ⅓ moisture.
(*g*) Hardwood charcoal.

Fig. 3.—En 32A. Carburised at 900° C. for 2 hours in various media and pot cooled. × 100

A number of chemical compounds are used as energisers, the most common being sodium carbonate, barium carbonate, and bone ash. These compounds are used either individually or in combination, and the amount added may vary from 3 to 50%—a somewhat remarkable range. The energiser may be added by an impregnation process, or as a coating on the surface of the charcoal with the aid of a suitable binder, such as molasses. It is remarkable that the majority of commercial compounds are still sold under trade names rather than to a specified composition.

Among the advantages claimed for coke-base compounds are a higher heat conductivity than pure charcoal-base compounds, together with lower dusting losses.

The size of compound used varies widely, and sizes are available commercially in the range ¼–⅝ in.

It is common practice to pack components with ½–1 in. spacing of compound between them, and to have a thicker layer of compound at the top of the container to allow for shrinkage of the carburising medium. Among the methods used to prevent exposure to the atmosphere of the top layer of components are (1) the placing of a metal sheet over the top of the compound, the sheet being covered with dust charcoal, and (2) the luting of the carburising container lid.

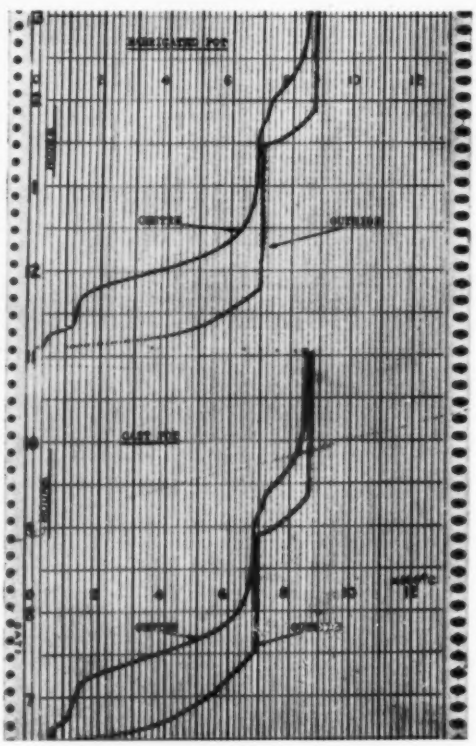
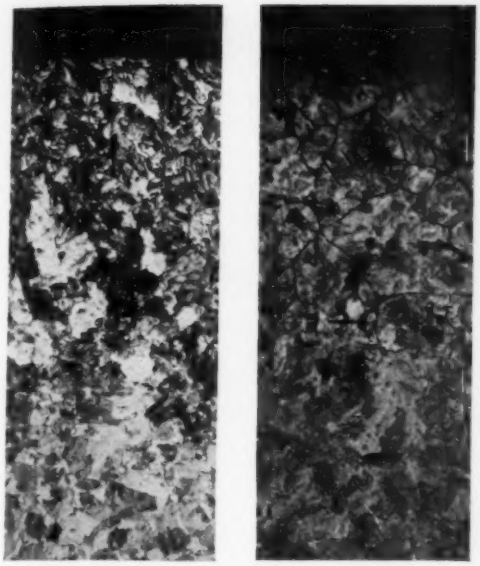


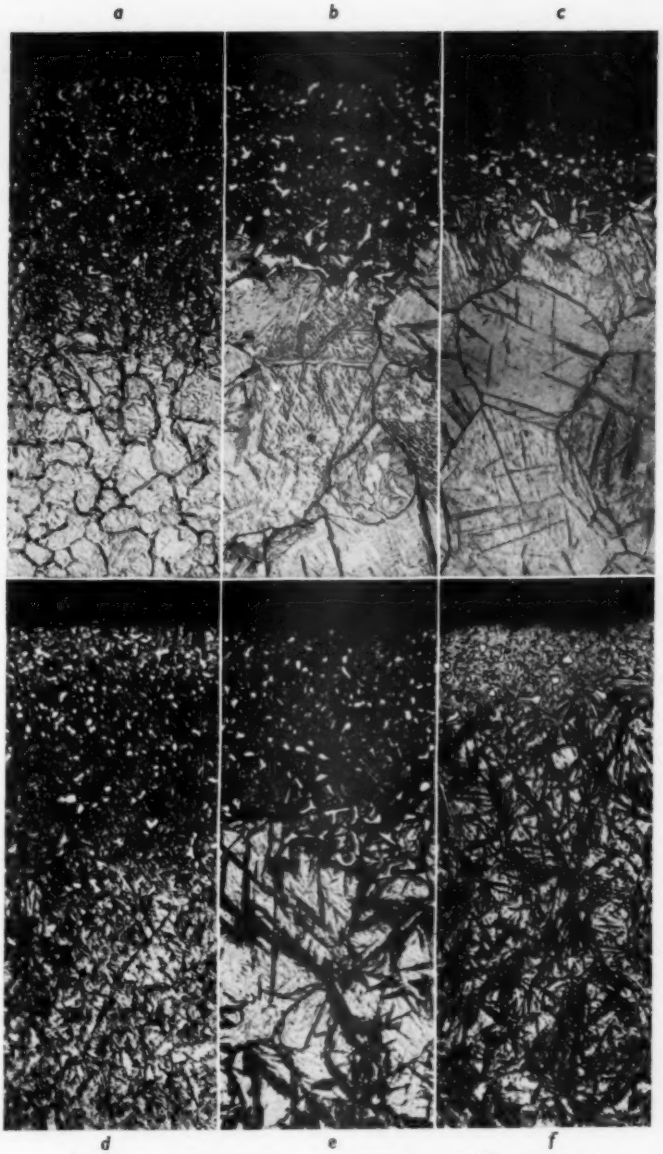
Fig. 2.—Heating rates of cast and fabricated containers.



(*a*) Used $2\frac{1}{2}$% $BaCO_3$ + 10% new.

(*b*) Used 5% Na_2CO_3 + 10% new.

Fig. 4.—En 32A. Carburised at 900° C. for 6 hours in various media and pot cooled. × 100



(*a*) 850° C. As carburised.
(*b*) 900° C. As carburised.
(*c*) 950° C. As carburised.
(*d*) 850° C. Double quenched.
(*e*) 900° C. Double quenched.
(*f*) 950° C. Double quenched.

Fig. 5.—En 39B. Carburised for 16 hours at various temperatures in used 5% Na_2CO_3 + 10% new compound. ×250

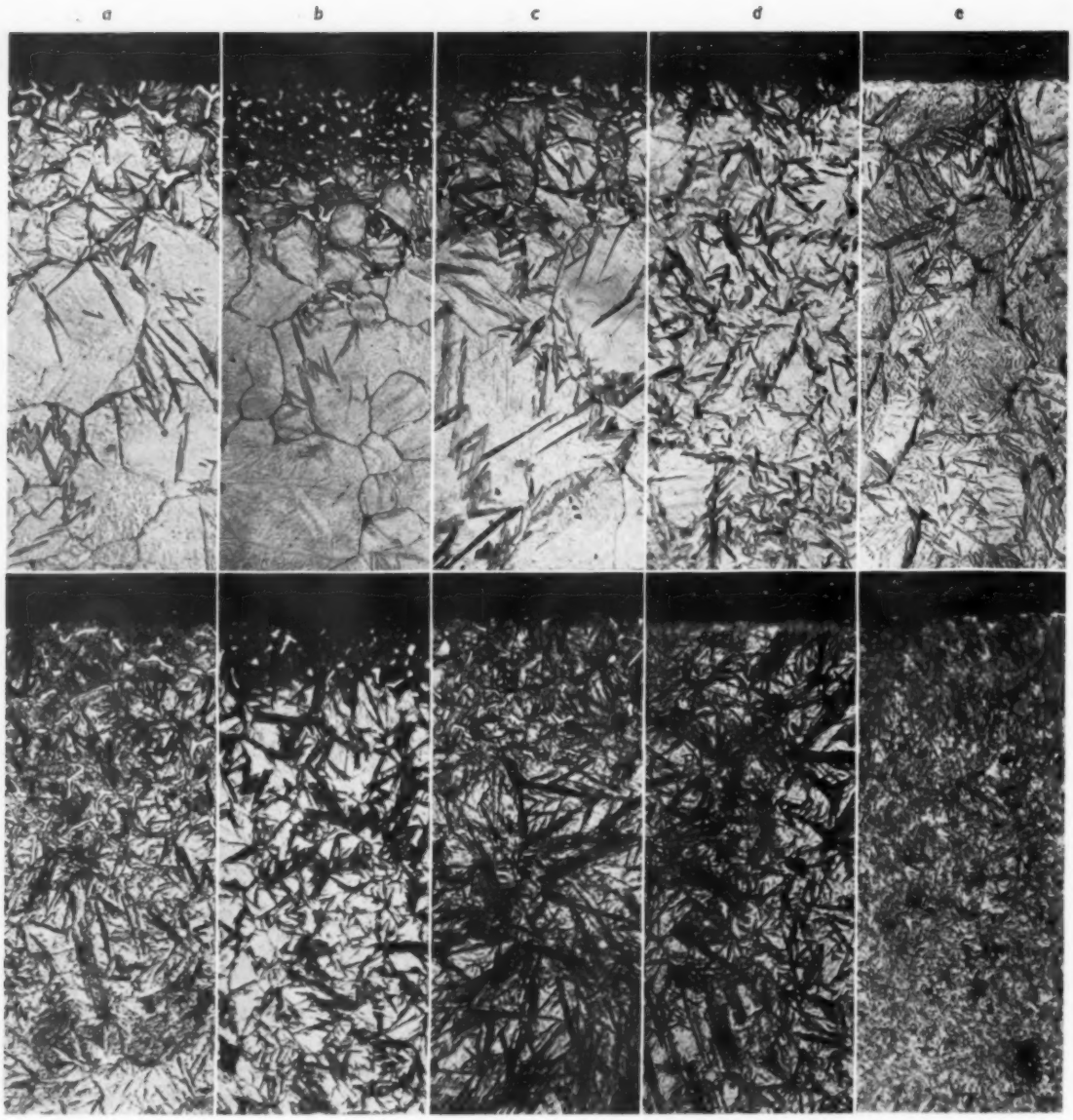
A variation of opinion exists as to the amount of new compound to be added in order to "regenerate" the used compound, and the amount added varies widely. In some instances an addition of 20% is made, whereas some shops have been known to use nothing but new compound.

Means employed for handling and screening compound vary from the manual sieve method to the vacuum-type screening unit known as the K.L. Controller as illustrated in Fig. 1. Manual screening methods tend to create a high energiser loss, particularly with the coated type of compound, and the automatic type screening equipment is to be commended, not only for the absence of this defect but because of cleaner operation. The belief has been expressed that both dust and moisture in carburising media are primary causes of outbreaks of low-carbon and "patchy" cases.

Heating Cycles.—The normal carburising temperatures in use vary from 880° C. to 920° C., although for alloy steels some heat treatment engineers prefer lower temperatures—of the order of 850° C. to 860° C. Preliminary soaking of a furnace load is sometimes used to equalise the temperature throughout both furnace load and

TABLE III.—COMPOSITION LIMITS OF STEELS USED FOR TESTS

Steel	C %	Si %	Mn %	P %	S %	Cr %	Mo %	Ni %
En 32A	0·18 max.	0·05–0·35	0·40–0·70	0·05 max.	0·05 max.	—	—	—
En 33	0·10–0·16	0·10–0·35	0·30–0·60	0·05 max.	0·05 max.	0·30 max.	—	2·75–3·50
En 34	0·14–0·20	0·10–0·35	0·30–0·60	0·05 max.	0·05 max.	—	0·20–0·30	1·50–2·00
En 35	0·20–0·28	0·10–0·35	0·30–0·60	0·05 max.	0·05 max.	—	0·20–0·30	1·50–2·00
En 36	0·18 max.	0·10–0·35	0·30–0·60	0·05 max.	0·05 max.	0·60–1·10	—	3·00–3·75
En 37	0·16 max.	0·10–0·35	0·45 max.	0·05 max.	0·05 max.	0·30 max.	—	4·50–5·20
En 39B	0·12–0·18	0·10–0·35	0·50 max.	0·05 max.	0·05 max.	1·00–1·40	0·15–0·35	3·80–4·50
En 201	0·18 max.	0·05–0·35	1·10–1·50	0·05 max.	0·05 max.	—	—	—
En 320	0·14–0·20	0·10–0·35	0·40–0·70	0·05 max.	0·05 max.	1·80–2·20	0·15–0·25	1·80–2·20
En 325	0·17–0·22	0·10–0·35	0·45–0·65	0·05 max.	0·05 max.	0·40–0·60	0·20–0·30	1·50–2·00
SL 660	0·10–0·16	0·3 max.	0·4 max.	0·06 max.	0·05 max.	0·45–0·75	—	4·50–5·50



(*a*) 3% Na_2CO_3. As carburised.
(*b*) Used 3% Na_2CO_3 + 10% new compound. As carburised.
(*c*) 2½% $BaCO_3$. As carburised.
(*d*) Used 2½% $BaCO_3$ + 10% new compound. As carburised.
(*e*) Used 5% $BaCO_3$ + 10% new compound. As carburised.
(*f*) 3% Na_2CO_3. Double quenched.
(*g*) Used 3% Na_2CO_3 + 10% new compound. Double quenched.
(*h*) 2½% $BaCO_3$. Double quenched.
(*i*) Used 2½% $BaCO_3$ + 10% new compound. Double quenched.
(*j*) Used 5% $BaCO_3$ + 10% new compound. Double quenched.

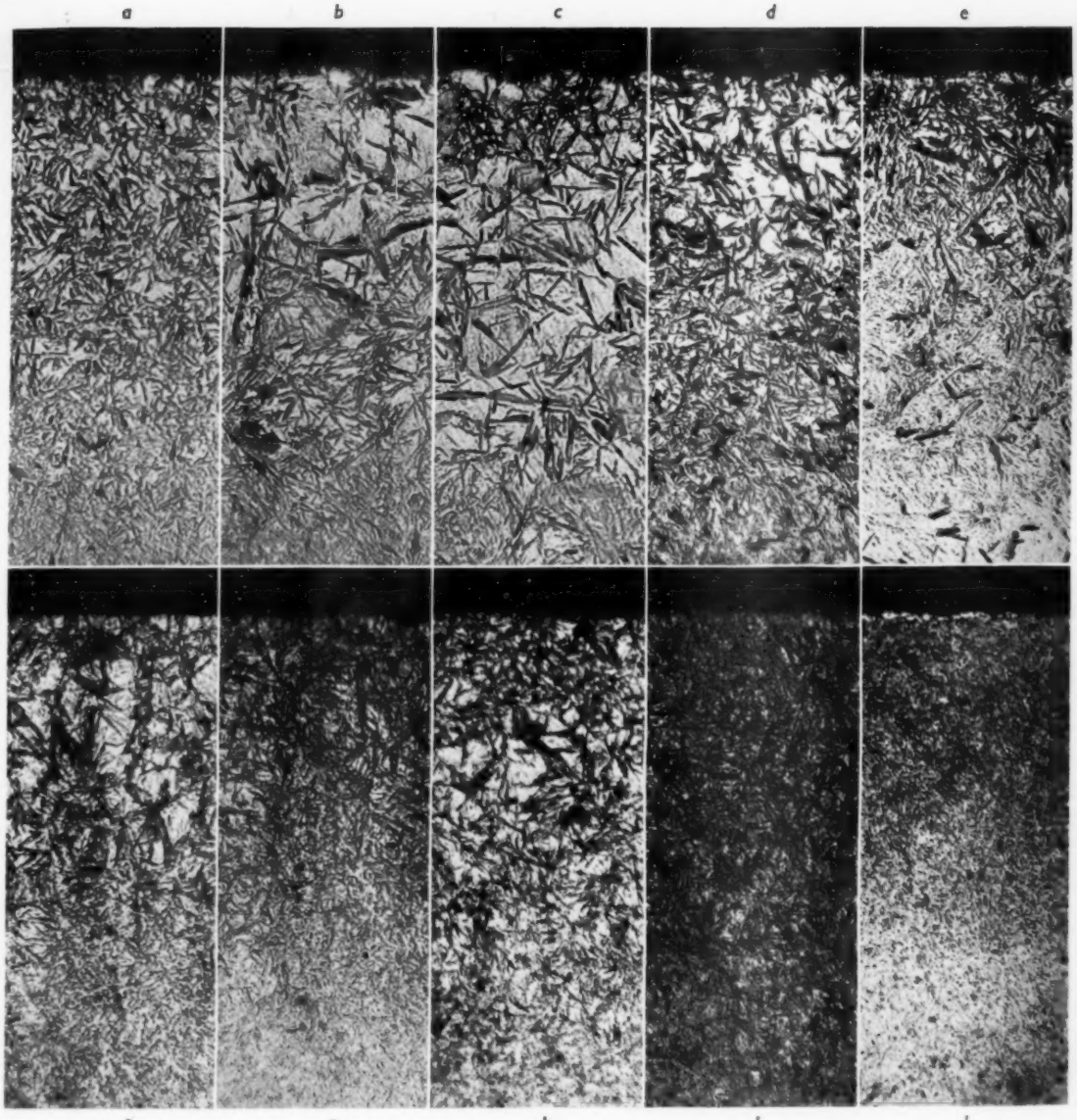
Fig. 6.—En 39B. Carburised for 16 hours at 900° C. in various media. × 250

carburising container. The soaking temperatures are normally in the range 600°C. to 800°C., and the practice is frequently employed when shallow cases (0·010–0·020 in.) are required to within close limits.

Carburising Containers.—The size and shape of the carburising pots are determined, to a large extent, by economic considerations, but much thought needs to be given to the shape if uniformity of treatment is to be achieved. Materials vary widely, from mild steel to nickel-chromium alloys, and overall costs usually determine the choice. Of recent years, containers fabricated from nickel-chromium sheet have been introduced and the belief exists that such containers have marked advantages over cast containers because they heat up more rapidly.

Details of Tests

Carburising Conditions.—All the compounds used in the experimental carburising were commercially manufactured and had a nominal size of ¼ in. Details of the various compounds are given in Table I and the results of tests on representative samples of three of them can



(*a*) 3% Na_2CO_3. As carburised.
(*b*) Used 3% Na_2CO_3 + 10% new compound. As carburised.
(*c*) 2½% $BaCO_3$. As carburised.
(*d*) Used 2½% $BaCO_3$ + 10% new compound. As carburised.
(*e*) Used 5% $BaCO_3$ + 10% new compound. As carburised.
(*f*) 3% Na_2CO_3. Double quenched.
(*g*) Used 3% Na_2CO_3 + 10% new compound. Double quenched.
(*h*) 2½% $BaCO_3$. Double quenched.
(*i*) Used 2½% $BaCO_3$ + 10% new compound. Double quenched.
(*j*) Used 5% $BaCO_3$ + 10% new compound. Double quenched.

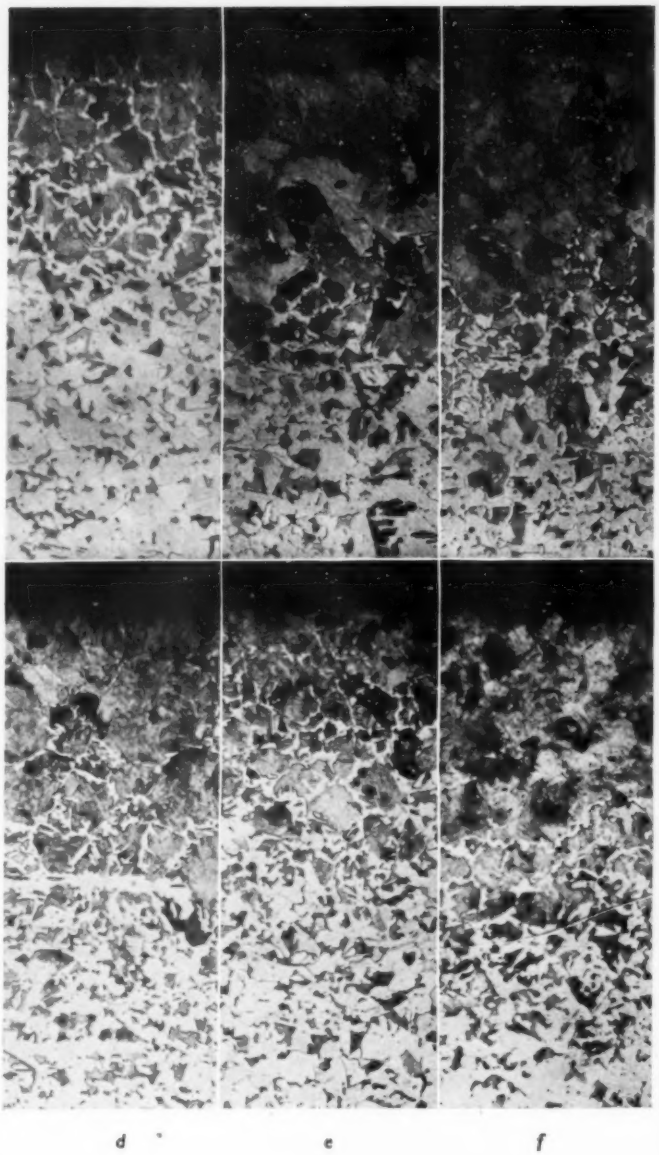
Fig. 7.—En 39B. Carburised for 2 hours at 900° C. in various media. × 250

be seen in Table II. With the exception of two special tests, a ratio of compound to work of 3 : 2 by weight was maintained, i.e. a spacing of approximately 1 in. between specimens or components. With the two special tests, a spacing of ¼ in. was used to give a ratio of compound to work of 3 : 4.

Steels.—The bulk of the investigation was confined to two steels, namely, En 32A and En 39B. In addition, confirmatory tests were made using En 33, En 34, En 35, En 36, En 37, En 201, En 320, En 325 and SL 660. The specification limits for the chemical composition of these steels are set out in Table III.

Heating Rate.—The time taken to reach temperature was measured at the centre of a 1 in. diameter bar, located in the middle of a carburising container fully loaded with carburising compound. Tests were made on fabricated and cast pots, both 8 in. long × 5½ in. wide × 5½ in. high, with the former ⅛ in. thick and the latter ¼ in. thick. The heating curves obtained are shown in Fig. 2.

Porcedure.—Test samples having dimensions similar to those encountered in light engineering practice, and which were conveniently available, were used throughout the series of tests. Carburising periods ranging from



(*a*) Severely used coke base.
(*b*) Severely used 10% $BaCO_3$.
(*c*) Severely used 5% Na_2CO_3.
(*d*) As (*a*) + 10% new compound.
(*e*) As (*b*) + 10% new compound.
(*f*) As (*c*) + 10% new compound.

Fig. 8.—En 32A. Carburised for 2 hours at 900° C. in " spent " compounds and pot cooled. × 100

two to sixteen hours, i.e. those which gave the depths of case normally called for in practice, were also adopted.

En 32A.—For the tests on steel En 32A, the test pieces took the form of washers having an outside diameter of 1·125 in., a 0·750 in. diameter hole, and a thickness of 0·340 in.

Two carburising procedures were adopted as detailed below under the numbers of the tables in which the results are recorded.

Tables IV, V, X, XIII and XIV.

(1) Pack in compound.
(2) Load into furnace at 650° C.
(3) Raise temperature to 800° C. and soak for 1 hour.
(4) Heat to carburising temperature and soak as stated.
(5) Remove pot from furnace and allow to cool.

Table XI.

(1) Pack in compound.
(2) Load into furnace at 650° C. and soak for 1 hour.
(3) Raise temperature and carburise for 2 hours at stated temperature.
(4) Remove pot from furnace and allow to cool.

The test pieces were refined and hardened by heating to 900° C. and oil quenching, followed by heating to 780° C. and water quenching.

Alloy Carburising Steels.—For tests on alloy steels the following test pieces were used :—

(*a*) For shallow case depths (up to 0·030 in.) on En 39B : washers having an outside diameter of 1·125 in., a 0·750 in. hole, and a thickness of 0·140 in.
(*b*) For heavier case depths (over 0·030 in.) on En 39B ; machined forgings with a diameter of 4 in. and a section of 1·25 in. × 0·50 in.
(*c*) For the final tests made with used 2½% and 5% barium carbonate compounds (Tables VII and IX), 1 in. diameter machined bars were used.

The carburising procedures adopted, again under the numbers of the tables in which the results are recorded, are detailed below.

Table XII.

(1) Pack in compound.
(2) Load into furnace at 650° C. and soak for 1 hour.
(3) Carburise as stated.

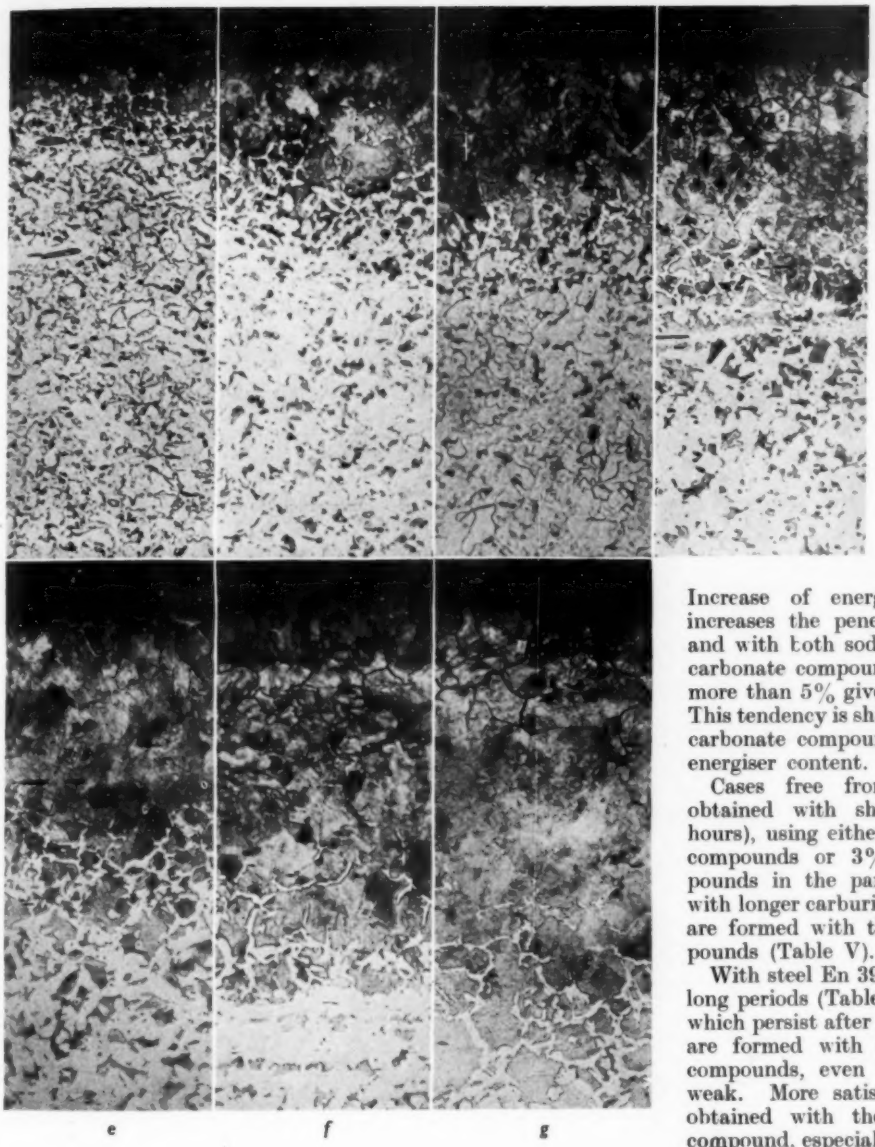
Tables VI, VII and IX.

(1) Pack in compound.
(2) Load into furnace at 650° C. and soak for 1 hour.
(3) Raise temperature to 800° C. and soak for 1 hour.
(4) Carburise as stated.

The test pieces were refined and hardened by heating to 860° C. and oil quenching, followed by heating to 770° C. and oil quenching, and a sub-zero treatment at −75° C. for 2 hours.

Examination of Test Pieces.—Case depths were measured on hardened specimens as well as on " as carburised " micro-specimens, and all samples were checked for the presence of carbide filaments by means of an alkaline sodium picrate etch.

In each test an examination was made of specimens taken from the side and centre positions at the top and bottom of the carburising container, but unless significant differences were noted, average figures have been given.



(*a*) 750° C.
(*b*) 800° C.
(*c*) 825° C.
(*d*) 850° C.
(*e*) 875° C.
(*f*) 900° C.
(*g*) 925° C.

Fig. 9.—En 32A. Carburised for 2 hours in used 5% Na_2CO_3 + 10% new compound, at various temperatures, and pot cooled. ×100

Discussion of Results

Type of Compound.—With plain carbon steels (Table IV) it is evident that, at equivalent strengths, sodium-base compounds have a greater tendency to produce carbide networks. Increase of energiser content above 5% increases the penetration rate only slightly, and with both sodium carbonate and barium carbonate compounds an energiser content of more than 5% gives rise to carbide networks. This tendency is shared by dust from a sodium-carbonate compound, by virtue of its higher energiser content.

Cases free from definite networks are obtained with short carburising cycles (2 hours), using either 2½–5% barium carbonate compounds or 3% sodium carbonate compounds in the partially used condition, but with longer carburising times definite networks are formed with the sodium carbonate compounds (Table V).

With steel En 39B, carburised for relatively long periods (Table VI), pronounced networks which persist after a double quench treatment, are formed with all the sodium carbonate compounds, even when these are relatively weak. More satisfactory types of case are obtained with the 2½% barium carbonate compound, especially when it is partially used. With carburising times shorter than 16 hours

TABLE IV—(EN 32A STEEL).— INFLUENCE OF NATURE OF CARBURISING MEDIUM UNDER CONSTANT CONDITIONS OF TIME (2 HOURS) AND TEMPERATURE (900° C.)

Type of Compound	Microstructure—As Carburised			Rockwell A Hardness of Hardened Specimen
	Hypereutectoid + Eutectoid Depth—in.	Total Depth—in.	Description	
2½% Barium Carbonate	0·012–0·014	0·024–0·028	Virtually no Fe_3C network.	83–84
5% Barium Carbonate	0·015–0·016	0·024–0·027	Slight network.	82–84
10% Barium Carbonate	0·013–0·017	0·024–0·029	Slight network.	82–85
15% Barium Carbonate	0·015–0·016	0·025–0·028	Definite network and patches of Fe_3C at edge.	82–86
3% Sodium Carbonate	0·014–0·015	0·025–0·028	Slight network.	82–84
5% Sodium Carbonate	0·015–0·017	0·023–0·025	Definite network.	82–85
Coke Base	0·015–0·016	0·028–0·030	Definite network.	82–86
Hardwood Charcoal	nil–0·004	0·016–0·017	Varies from 0·6% C. at top to eutectoid at bottom of container.	82–84
Compound Dust (22% Sodium Carbonate)	0·012–0·014	0·022–0·025	Definite network.	82–85

TABLE V—(EN 32A STEEL).—INFLUENCE OF NORMAL USAGE (ONE CARBURISING CYCLE OF 6 HOURS AT 900° C.) AND REGENERATION ON VARIOUS CARBURISING MEDIA

Type of Compound	Carburising Treatment	Microstructure—As Carburised			Rockwell A Hardness of Hardened Specimen
		Hypereutectoid + Eutectoid Depth—in.	Total Depth—in.	Description	
2½% Barium Carbonate. Used + 10% New	900° C. × 2 hr.	0·010	0·021	Eutectoid	84–85
5% Barium Carbonate. Used + 10% New	900° C. × 2 hr.	0·015	0·026	Occasional broken networks at edge.	84–85
3% Sodium Carbonate. Used + 10% New	900° C. × 2 hr.	0·012	0·026	Slight Fe_3C network.	84–86
3% Sodium Carbonate. Used + 10% New	925° C. × 2 hr.	0·016	0·028	Pronounced network.	85–86
2½% Barium Carbonate. Used + 10% New	900° C. × 6 hr.	0·023	0·037	Eutectoid	84–86
5% Barium Carbonate. Used + 10% New	900° C. × 6 hr.	0·025	0·054	Fine network.	83–84
5% Sodium Carbonate. Used + 10% New	900° C. × 6 hr.	0·024	0·038	Pronounced network.	84–86
3% Sodium Carbonate. Used + 10% New	900° C. × 6 hr.	0·022	0·038	Definite network.	84–85
3% Sodium Carbonate. Used + 10% New	925° C. × 6 hr.	0·029	0·046	Pronounced network and needles of Fe_3C.	84–86
2½% Barium Carbonate. Used + 10% New	900° C. × 16 hr.	0·034	0·070	Fine films of Fe_3C.	84
5% Barium Carbonate. Used + 10% New	900° C. × 16 hr.	0·035	0·076	Definite network	85–86

TABLE VI—(EN 39B STEEL).—INFLUENCE OF NATURE OF CARBURISING MEDIUM UNDER VARIOUS CONDITIONS OF TIME AND TEMPERATURE.

Type of Compound	Carburising Treatment	Hardened Specimen			Microstructure	
		Case Depth in.	V.P.N. as Quenched	V.P.N. after Sub-zero Treatment	As Carburised	As Double Quenched
5% Sodium Carbonate. Used + 10% New ..	850° C. × 16 hr.	0·058	858	960	Heavy broken network of Fe_3C at edge. Pronounced network below.	Network persists.
5% Sodium Carbonate. Used + 10% New ..	900° C. × 16 hr.	0·084	813	960	Chunky Fe_3C network at edge.	Network persists.
5% Sodium Carbonate. Used + 10% New ..	950° C. × 16 hr.	0·096	835	933	Broken network at edge. Pronounced network below.	Network persists.
Coke Base	900° C. × 16 hr.	0·048	803–824		Chunky Fe_3C network at edge.	—
5% Sodium Carbonate 'Used'	900° C. × 16 hr.	0·060	792		Small amount of chunky network.	—
2½% Barium Carbonate	900° C. × 16 hr.	0·056	847–858	933–946	No heavy network. Pronounced broken network of Fe_3C at edge.	Patches of Fe_3C at edge.
2½% Barium Carbonate. Used + 10% New ..	900° C. × 16 hr.	0·052	803	940	No network.	No network.
3% Sodium Carbonate	900° C. × 16 hr.	0·058	858	933–940	Chunky network.	Network persists.
3% Sodium Carbonate. Used + 10% New ..	900° C. × 16 hr.	0·048	803	946	Chunky network.	Network persists.
Hardwood Charcoal	900° C. × 16 hr.	0·060	665		Low carbon martensite.	—
2½% Barium Carbonate. Used + 10% New ..	900° C. × 6 hr.	0·032	813		No network.	No network.
3% Sodium Carbonate. Used + 10% New ..	900° C. × 6 hr.	0·032	808		No network.	No network.
2½% Barium Carbonate	900° C. × 2 hr.	0·018	813	933	Occasional patches of Fe_3C.	Mainly martensite. Occasional patches of Fe_3C.
2½% Barium Carbonate. Used + 10% New ..	900° C. × 2 hr.	0·018	813		No network.	Mainly martensite. No network.
3% Sodium Carbonate	900° C. × 2 hr.	0·018	813	933	Occasional patches of Fe_3C.	Mainly martensite. Occasional patches of Fe_3C.
5% Sodium Carbonate. Used + 10% New ..	900° C. × 2 hr.	0·018	808		No network.	Mainly martensite. No network.

TABLE VII—(ALLOY STEELS).—NATURE OF CASE OBTAINED ON ALLOY STEELS WITH CONSTANT TEMPERATURE (900° C.) AND CARBURISING MEDIUM (USED 2½% BARIUM CARBONATE + 10% NEW) USING VARIOUS CARBURISING TIMES

Steel	Carburising Time	Microstructure		Hardened Specimen	
		As Carburised	As Double Quenched 860°–770° C. Oil	Case Hardness V.P.N.	Case Depth —in.
SL 660	2 hr.	No network.	No network on any specimen.	824	0·020
EN 34	2 hr.	No network.		824	0·020
EN 33	2 hr.	No network.		810–825	0·018
EN 39B	2 hr.	No network.		810	0·018–0·020
SL 660	6 hr.	No network.		810	0·034–0·036
EN 34	6 hr.	No network.		849	0·032–0·036
EN 33	6 hr.	No network.		849–857	0·032
EN 39B	6 hr.	No network.		810–817	0·040
SL 660	16 hr.	No network.		803	0·060
EN 34	16 hr.	No network.		825–833	0·060
EN 33	16 hr.	Faint carbide film.		825–833	0·060
EN 39B	16 hr.	Fine carbide film.		810–817	0·058

satisfactory cases free from networks are produced with partially used 3% sodium carbonate or 2½% barium carbonate compounds.

Other alloy carburising steels (Tables VII and VIII) are carburised satisfactorily in a partially used 2½% barium carbonate compound, and, except for the long carburising cycle (16 hours), cases free from networks are also obtained on alloy steels using weak 5% barium carbonate compound (Table IX).

Coke-base compounds have not been examined to any great extent as they exhibit marked separational tendencies when suction filtering plant is used.

Strength or Dilution.—Extremely severe usage can be given to all types of carburising compound before the carburising action suffers any substantial deterioration (Table X). An addition of 10% new compound is sufficient to restore normally used compound to its original activity (*c.f.* Tables IV and V).

Temperature.—Some carbon penetration occurs at 750° C., and at 800° C. carburising proceeds at a rate of 0·005 in. per hour (Tables XI and XII). An abrupt transition from case to core occurs with plain carbon steels when the carburising temperature is below 850° C., and at temperatures above 950° C. pronounced carbide

TABLE VIII.—RESULTS OF CARBURISING TESTS ON 1 in. DIAMETER GROUND BAR.

Steel.			19% Barium Carbonate 1% Calcium Carbonate Carburising Compound.						Lucas Carburising Compound–2½% Barium Carbonate					
			100% New Compound			90% Used Compound 10% New Compound			100% New Compound			90% Used Compound 10% New Compound		
En No.	Mark	Type	Case Depth in.*	Carbide Filaments **	Massive Carbide **	Case Depth in.*	Carbide Filaments **	Massive Carbide **	Case Depth in.*	Carbide Filaments **	Massive Carbide **	Case Depth in.*	Carbide Filaments **	Massive Carbide **
32A	IXC	Carbon		Medium—thick 0·020 in.	None		Thin 0·018 in.	None		None	None		None	None
33	IXH	3% Ni		Thin but continuous 0·025 in.	None		Thin 0·020 in.	None		Traces at edge	None		Very faint traces at edge	None
34	IYG	2% Ni-Mo		Medium 0·018 in	None.		Thin 0·018 in.	None		Faint traces at edge	None		None	None
35	IYI	2% Ni-Mo (High C)		Medium—thick 0·022 in.	None		Thin 0·018 in.	None		Traces at edge	None		None	None
36	IYA	3% Ni-Cr	0·074	Thick 0·025 in.	Coarse—in patches 0·006 in.	0·066	Medium—thin 0·020 in.	Fairly coarse in patches <·003in.	0·058	None	None	0·057	None	None
37	MHH	5% Ni		Thin 0·018 in.	None		Thin 0·014 in.	None		Traces at edge	None		None	None
38	IXI	5% Ni (Mo)		Very thin discontinuous	None		Very faint traces	None		None	None		Faint traces at edge	None
39B	IXU	4½% Ni-Cr-Mo	0·084	Thin 0·022 in.	Small patches	0·080	Thin 0·020 in.	None	0·073	Traces at edge	None	0·062	None	None
201	IZE	C-Mn		Medium 0·028 in.	Medium-continuous 0·016 in.		Medium 0·022 in.	None		None	None		None	None
320	IYC	2% Ni (2% Cr-Mo)	0·066	Medium 0·030 in.	Very coarse—continuous 0·008 in.	0·064	Thin 0·014 in.	Very coarse—continuous 0·005 in.	0·059	None	None	0·053	Faint traces at edge <0·003 in.	None
325	NMG	1½% Ni-Cr-Mo		Very thick 0·033 in.	Coarse—in patches 0·002 in.		Thick 0·026 in.	Medium—in patches ≤ 0·003 in.		Medium—thin discontinuous 0·020 in.	None		Traces at edge <0·003 in.	None

* Estimated from macro-etch appearance as carburised.
** The figures given in these columns indicate the average depth of penetration below the surface. Ex. Mond Nickel.

TABLE IX—(ALLOY STEELS).—NATURE OF CASE OBTAINED ON ALLOY STEELS WITH CONSTANT TEMPERATURE (900° C.) AND CARBURISING MEDIUM (USED 5% BARIUM CARBONATE + 10% NEW) USING VARIOUS CARBURISING TIMES

Steel	Carburising Time	Microstructure		Hardened Specimen	
		As Carburised	As Double Quenched 860°–770° C. Oil	Case Hardness V.P.N.	Case Depth—in.
SL 660	2 hr.	No network.	No network on any specimen.	762	0·024
EN 34	2 hr.	No network.		858	0·024
EN 33	2 hr.	No network.		824	0·024–0·026
EN 39B	2 hr.	No network.		858	0·020–0·024
SL 660	6 hr.	No network.		858	0·036–0·040
EN 34	6 hr.	No network.		858	0·036–0·040
EN 33	6 hr.	No network.		803	0·040–0·042
EN 39B	6 hr.	No network.		824	0·040
SL 660	16 hr.	No network.		824	0·060
EN 34	16 hr.	No network.		858	0·064
EN 33	16 hr.	Faint films of carbide.		858	0·056
EN 39B	16 hr.	Persistent carbide films.		813	0·060

TABLE X—(EN 32A STEEL).—INFLUENCE OF SEVERE USAGE (FIVE SUCCESSIVE CARBURISING CYCLES OF 6 HOURS AT 900° C. WITHOUT ADDITIONS OF NEW COMPOUND) ON VARIOUS CARBURISING MEDIA.

Type of Compound	Carburising Treatment	Microstructure—As Carburised			Rockwell A Hardness of Hardened Specimen
		Hypereutectoid + Eutectoid Depth—in.	Total Depth in.	Description	
Coke Base. Used	900° C. × 2 hr.	nil	0·015–0·016	Low carbon case	80–84
10% Barium Carbonate. Used	900° C. × 2 hr.	0·010–0·011	0·020	Eutectoid	81–84
5% Sodium Carbonate. Used	900° C. × 2 hr.	0·010–0·011	0·020–0·021	Eutectoid	82–85
Coke Base. Used + 10% New	900° C. × 2 hr.	0·006–0·010	0·019–0·020	Mainly eutectoid	82–84
10% Barium Carbonate. Used + 10% New	900° C. × 2 hr.	edge only	0·018–0·020	Eutectoid at edge only.	82–84
5% Sodium Carbonate. Used + 10% New	900° C. × 2 hr.	0·012–0·014	0·020–0·024	Eutectoid	82–85

networks are produced, even with weak compound.

With alloy steels, there is a tendency to build up a layer of solid Fe_3C at the extreme surface with carburising temperatures below 850° C.

With all the steels examined, a carburising range of 875°C. to 900°C. is the most suitable, and at all temperatures weaker compound has less tendency to form carbide layers or networks.

Moisture.—The addition of a high percentage of moisture increases the rate of penetration and the tendency to form carbide networks (Table XIII). Other aspects of this factor need to be borne in mind, however, as will be seen later.

Heating Rate.—Although the outside of a fabricated pot reaches temperature somewhat earlier than that of a cast pot (Fig. 2), a 2-hour period from loading time

TABLE XI—(EN 32A STEEL).—INFLUENCE OF TEMPERATURE UNDER CONSTANT CONDITIONS OF TIME (2 HOURS) AND CARBURISING MEDIUM (5% SODIUM CARBONATE)

Compound Used	Carburising Treatment (After 1 hr. Soak at 650° C.)	Microstructure—As Carburised			Rockwell A Hardness of Hardened Specimen
		Hyper-eutectoid + Eutectoid Depth—in.	Total Depth—in.	Description	
5% Sodium Carbonate. Unused ..	700° C. × 2 hr.	nil	0·001–0·0015	Slight carbon penetration.	75–78
5% Sodium Carbonate. Unused ..	750° C. × 2 hr.	nil	0·004	Almost eutectoid.	76–78
5% Sodium Carbonate. Unused ..	800° C. × 2 hr.	0·006	0·008	Eutectoid case. Abrupt tran ition.	81–83
5% Sodium Carbonate. Unused ..	825° C. × 2 hr.	0·007	0·010	Eutectoid case.	82–83
5% Sodium Carbonate. Unused ..	850° C. × 2 hr.	0·008	0·012	Slight Fe_3C network.	83–86
5% Sodium Carbonate. Unused ..	875° C. × 2 hr.	0·015	0·022	Definite Fe_3C network, build up of solid Fe_3C at edge.	84–85
5% Sodium Carbonate. Unused ..	900° C. × 2 hr.	0·019	0·024	Pronounced Fe_3C network.	85–86
5% Sodium Carbonate. Unused ..	925° C. × 2 hr.	0·020	0·030	Pronounced Fe_3C network.	83–85
5% Sodium Carbonate. Used + 10% New	700° C. × 2 hr.	nil	nil	No carbon increase.	63–68
5% Sodium Carbonate. Used + 10% New	750° C. × 2 hr.	nil	0·002–0·003	Slight carbon penetration.	83–84
5% Sodium Carbonate. Used + 10% New	800° C. × 2 hr.	0·004	0·007	Abrupt transition.	81–82
5% Sodium Carbonate. Used + 10% New	825° C. × 2 hr.	0·005	0·012	Eutectoid at surface fairly abrupt transition.	81–83
5% Sodium Carbonate. Used + 10% New	850° C. × 2 hr.	0·009	0·017	Definite Fe_3C network.	83–85
5% Sodium Carbonate. Used + 10% New	875° C. × 2 hr.	0·012	0·020	Definite Fe_3C network.	84–85
5% Sodium Carbonate. Used + 10% New	900° C. × 2 hr.	0·015	0·022	Definite Fe_3C network.	82–84
5% Sodium Carbonate. Used + 10% New	925° C. × 2 hr.	0·018	0·030	Pronounced Fe_3C network.	83–87

TABLE XII—(EN 39B STEEL).—INFLUENCE OF TEMPERATURE UNDER CONSTANT CONDITIONS OF TIME (2 HOURS) AND CARBURISING MEDIUM (5% SODIUM CARBONATE)

Type of Compound	Carburising Treatment	Hardened Specimen				Microstructure—As Carburised
		Case Depth—in.	Hardness			
			As Quenched		After Sub-zero Treatment V.P.N.	Description
			Rockwell A	V.P.N.		
5% Sodium Carbonate. Unused	700° C. × 2 hr.	0·001	71	—	—	Slight carbon increase at edge.
5% Sodium Carbonate. Unused	750° C. × 2 hr.	0·005	80	—	—	Carbide build up at edge. Martensitic case.
5% Sodium Carbonate. Unused	800° C. × 2 hr.	0·012	81–82	—	—	Solid Fe_3C at edge.
5% Sodium Carbonate. Unused	825° C. × 2 hr.	0·012–0·016	82–83	—	—	Thick broken layer of Fe_3C.
5% Sodium Carbonate. Unused	850° C. × 2 hr.	0·018–0·020	83–84	835	882	Thick broken network of Fe_3C at edge.
5% Sodium Carbonate. Unused	875° C. × 2 hr.	0·024	82–83	772	870	Broken network of Fe_3C.
5% Sodium Carbonate. Unused	900° C. × 2 hr.	0·024	81–83	858	875	Broken network of Fe_3C. Network extending in.
5% Sodium Carbonate. Unused	925° C. × 2 hr.	0·030–0·032	82–83	777	882	Broken network of Fe_3C. Network extending in.
5% Sodium Carbonate. Used + 10% New	700° C. × 2 hr.	Nil	73–74	—	—	No carbon penetration.
5% Sodium Carbonate. Used + 10% New	750° C. × 2 hr.	0·003	78	—	—	Low carbon. Martensitic at edge.
5% Sodium Carbonate. Used + 10% New	800° C. × 2 hr.	0·007	81–83	—	—	Martensitic case. Some austenite.
5% Sodium Carbonate. Used + 10% New	825° C. × 2 hr.	0·012	83–84	—	—	Martensitic case. Traces of network. Austenite.
5% Sodium Carbonate. Used + 10% New	850° C. × 2 hr.	0·016–0·018	83	808	882	Broken network. Austenite marked.
5% Sodium Carbonate. Used + 10% New	875° C. × 2 hr.	0·020–0·022	81–83	788	872	Pronounced austenite rim. Network of Fe_3C.
5% Sodium Carbonate. Used + 10% New	900° C. × 2 hr.	0·018	82	734	872	Small Fe_3C broken network extending in. Pronounced Austenite.
5% Sodium Carbonate. Used + 10% New	925° C. × 2 hr.	0·024–0·026	79–80	740	882	Small Fe_3C broken network extending in. Pronounced Austenite.

TABLE XIII—(EN 32A STEEL).—INFLUENCE OF MOISTURE. CARBURISED AT 900° C. FOR 2 HOURS.

Type of Compound	Microstructure—As Carburised			Rockwell A Hardness of Hardened Specimen
	Hyper-eutectoid + Eutectoid Depth—in.	Total Depth—in.	Description	
10% Barium Carbonate. New compound	0·013–0·017	0·024–0·029	Slight network.	82–85
10% Barium Carbonate. 5/6 compound 1/6 water (by wt.) ..	0·014–0·018	0·023–0·025	Pronounced network.	82–85
10% Barium Carbonate. 2/3 compound 1/3 water (by wt.) ..	0·017–0·020	0·025–0·029	Pronounced network.	82–85
5% Sodium Carbonate. New compound	0·015–0·017	0·023–0·025	Definite network.	82–85
5% Sodium Carbonate. 5/6 compound 1/6 water (by wt.) ..	0·017–0·019	0·026–0·030	Pronounced network.	83–85
5% Sodium Carbonate. 2/3 compound 1/3 water (by wt.) ..	0·015–0·017	0·026–0·028	Pronounced network.	82–86

is necessary in each instance for the centre to attain the equalising temperature with the size of container in question.

Packing and Spacing.—Well-fitting lids are effective seals for the container, but the loss of a lid becomes disastrous. Loose packing, or air space in the container, causes lack of uniformity, but closer spacing of test pieces has no marked effect (Table XIV).

Conclusions

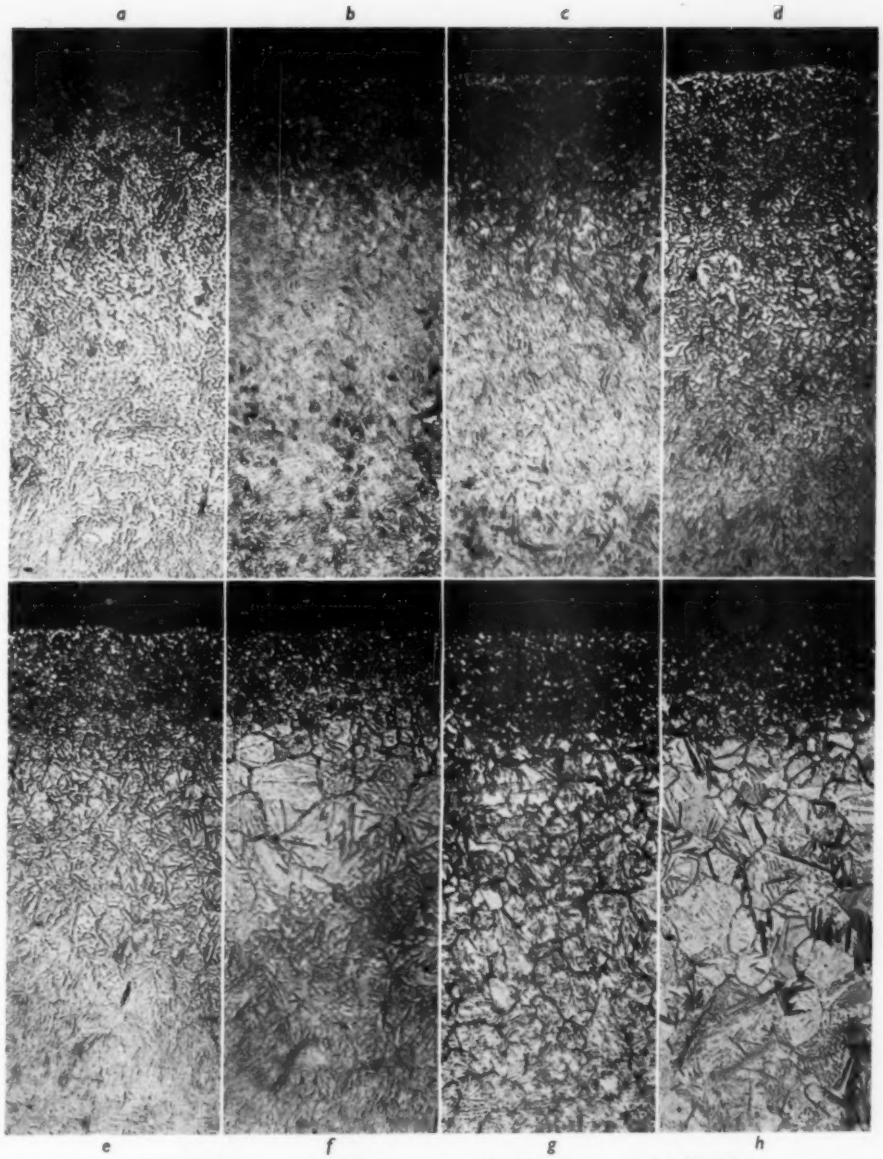
Barium carbonate compounds are less prone to give excess carbide than sodium carbonate compounds. Energiser contents above 5% appear to be unnecessary, and it has been established that additions of 10% new compound regenerate adequately a normally used medium.

A hardwood charcoal-base compound, with 2½%

barium carbonate as energiser, appears to be a satisfactory medium for carburising the alloy case-hardening steels without the formation of excess carbide. The energiser could probably be increased to nearly 5% barium carbonate without detriment, a compound with a sodium carbonate content slightly less than the 3% tested might also be successful in avoiding networks.

With compounds having low energiser contents, it is even more essential that the chemical should be adequately bonded to the charcoal to avoid loss under production conditions. Dust does not cause lowering of case carbon, but the high percentage of energiser present will cause locally high penetration rates, and could lead to fusion of thin sections or edges.

If well-fitting container lids are used, luting becomes unnecessary, and this prevents the pollution of the compound with clay. The use of fabricated containers, in preference to cast ones, does not reduce the time necessary for the centre of the pot to reach temperature. This is not unexpected, as the time required is a function of the mass of low-conductivity carburising compound in which the parts are embedded, rather than of the thickness of the container wall.



(*a*) 700° C. (*b*) 750° C. (*c*) 800° C. (*d*) 825° C. (*e*) 850° C. (*f*) 875° C. (*g*) 900° C. (*h*) 925° C.

Fig. 10.—En 39B. Carburised for 2 hours in new 5% Na_2CO_3 compound at various temperatures and pot cooled. × 250

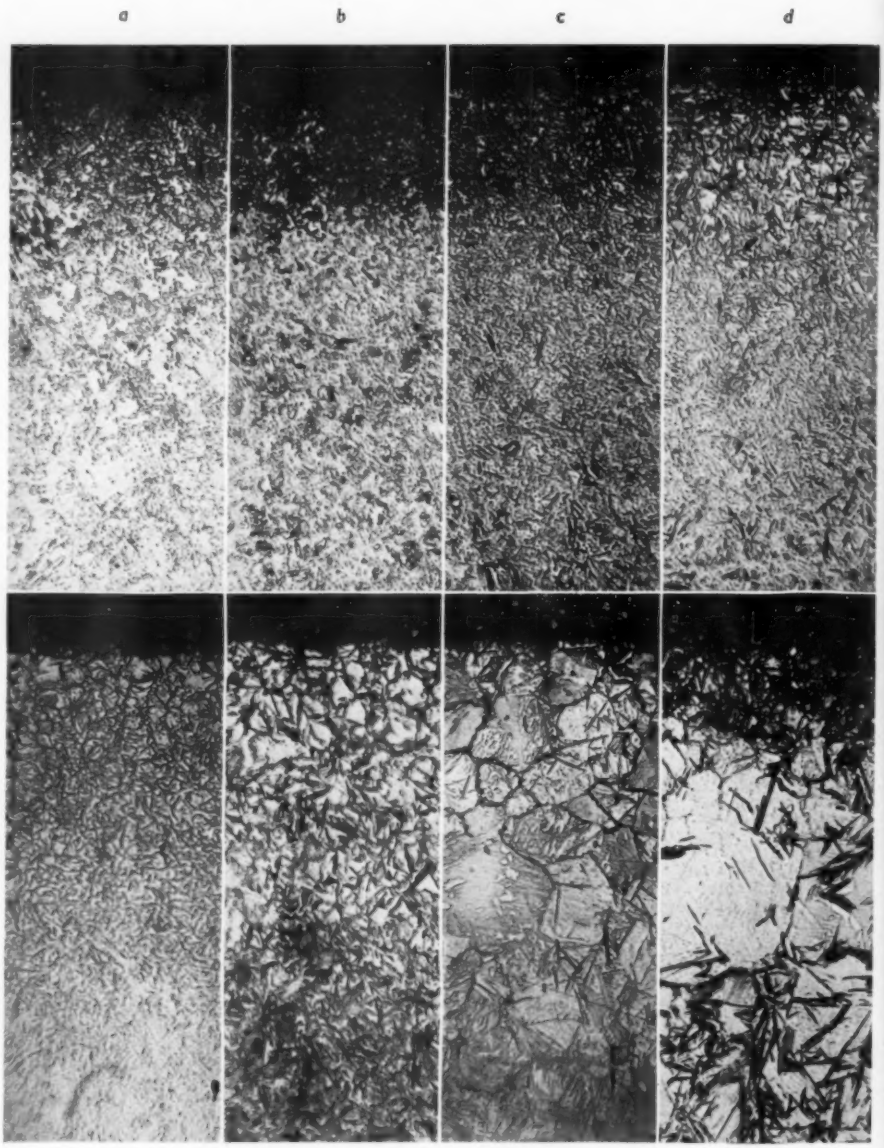
TABLE XIV—(EN 32A STEEL).—INFLUENCE OF PACKING AND SPACING. CARBURISED AT 900° C. FOR 2 HOURS.

Type of Compound	Microstructure—As Carburised			Rockwell A Hardness of Hardened Specimen
	Hypereutectoid + Eutectoid Depth—in.	Total Depth—in.	Description	
5% Sodium Carbonate. New Compound. Normal Packing—1 in. Spacing	0·015–0·017	0·023–0·025	Definite network.	82–85
5% Sodium Carbonate. New Compound. ¼ in. Spacing	0·015–0·017	0·020–0·021	Definite network.	83–86
5% Sodium Carbonate. New Compound. Lid not Luted	0·016–0·019	0·023–0·025	Definite network.	82–84
5% Sodium Carbonate. New Compound. 1 in. Space at Top of Pot	Bottom 0·019 Top 0·015	0·026 0·023	Definite network.	83–84 83–84
5% Sodium Carbonate. New Compound. No Lid on Pot	Bottom 0·015 Top nil. 0·015	0·027 nil. 0·022	Definite network. No penetration. Definite network.	83–85 55–78 82–84
Used 5% Sodium Carbonate + 10% New. 1 in. Spacing	0·014–0·016	0·018–0·021	Definite network.	83–85
Used 5% Sodium Carbonate + 10% New. ¼ in. Spacing				

Uniformity of case and economy in time can only be effected by suiting the shape and size of the carburising container to the parts in question. Fabricated containers have, of course, obvious advantages in case of "tailoring" to a component and lightness of handling.

A load equalisation temperature of 700° C. to 750° C. would appear to be the most suitable when close control is required since, above this temperature, penetration rates are sufficiently high to cause non-uniformity throughout the furnace load. With alloy steels, the use of lower carburising temperature than the commercial practice of 880° C. to 900° C. has no advantages and leads to the production of layers of massive carbide.

Moisture does not cause low carbon or "patchy" cases, but increases the penetration rate and network forming tendency. Other effects associated with moisture must, however, be considered. In the first place, components packed in wet compound, and left for any considerable time, will develop an anti-carburising oxide film. Secondly, a high moisture content may indicate that storage conditions are poor and that, in consequence, the energiser may have been washed out of the compound, or perhaps, concentrated at the bottom of the sack. A moisture content of 4–6% indicates that the carburising medium has not been over-dried during the bonding of the energiser, and will not have marked moisture absorbing tendencies.



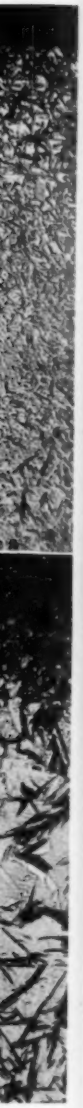
(a) 700° C. (b) 750° C. (c) 800° C. (d) 825° C. (e) 850° C. (f) 875° C. (g) 900° C. (h) 925° C.

Fig. 11.—En 39B. Carburised for 2 hours in used 5% Na_2CO_3 + 10% new compound at various temperatures and pot cooled. × 250

No tests were made on the influence of compound size, but increasing the particle size will bring about better gas circulation within the container. The compound chosen should, therefore, have the largest possible particle size consistent with (1) providing adequate support for components likely to distort; (2) allowing the components to be conveniently separated from the compound when unpacking; and (3) preventing components from settling at the bottom of the container during handling.

Acknowledgments

The author is indebted to Messrs. Joseph Lucas, Ltd., for permission to publish this article, and to Messrs. Gibbons Wild-Barfield, Ltd., for supplying the special barium-base compounds used during the tests. Thanks are also due to the Mond Nickel Company for making the confirmatory tests detailed in Table VIII.



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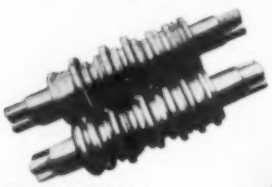

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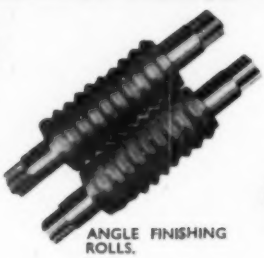

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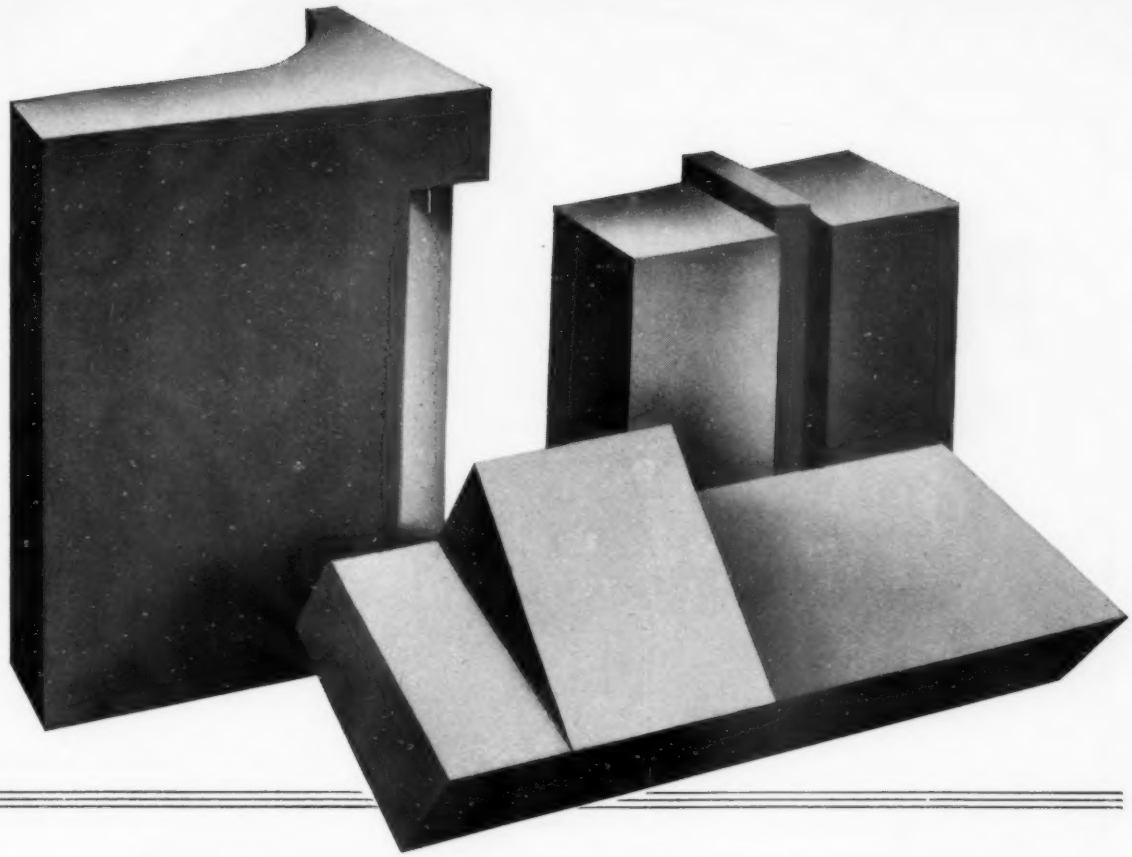

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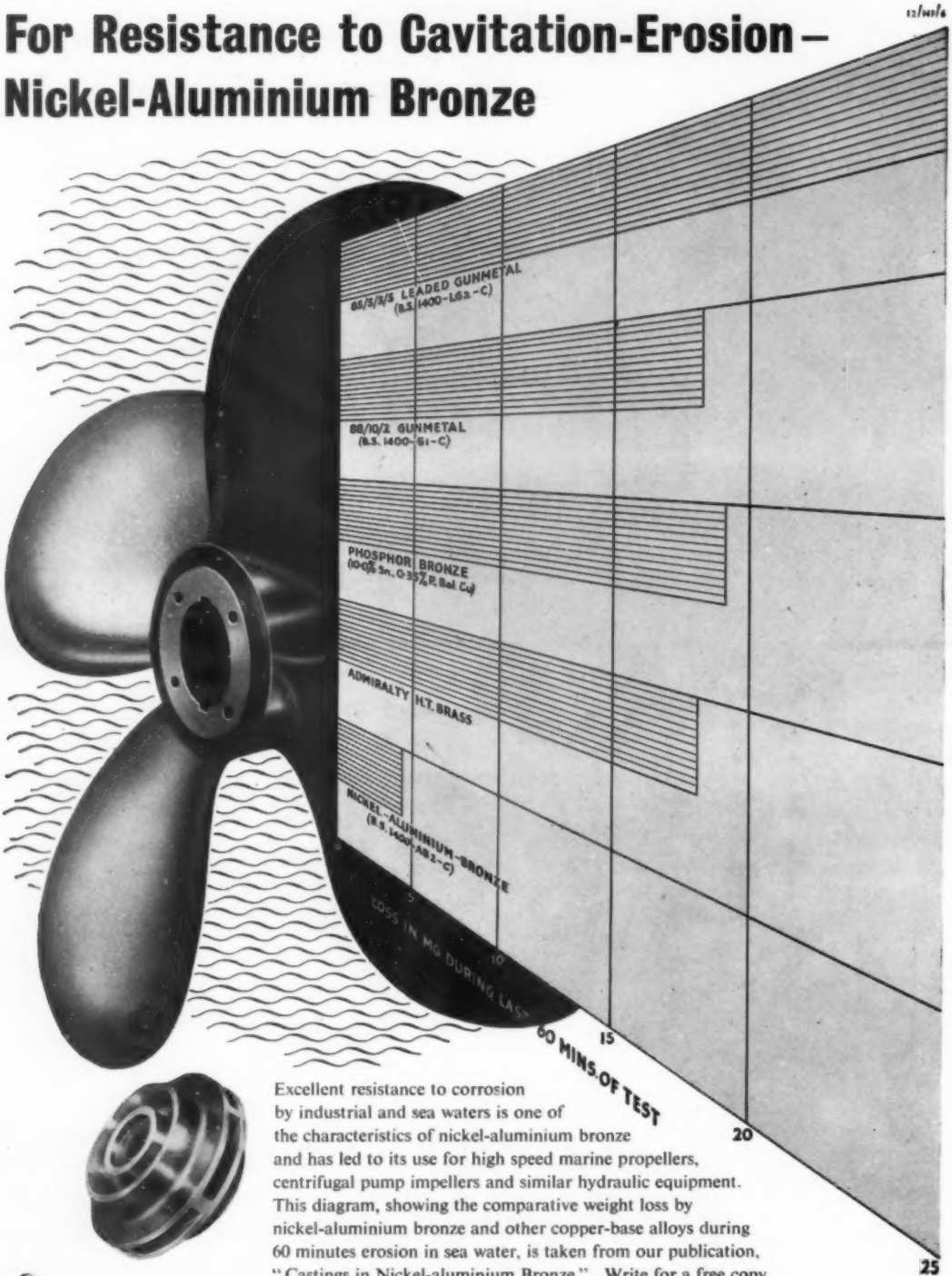

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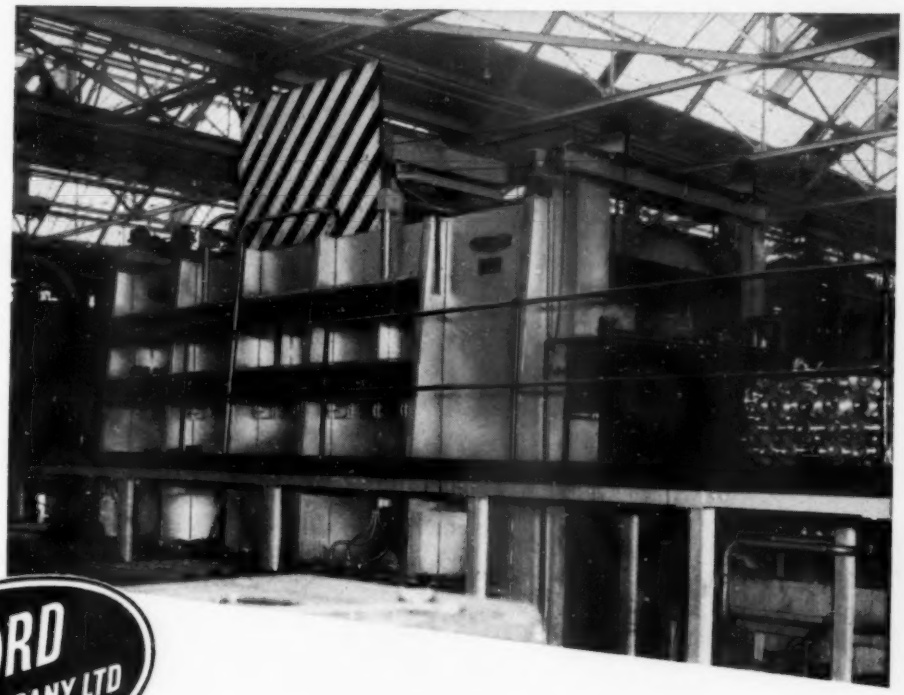

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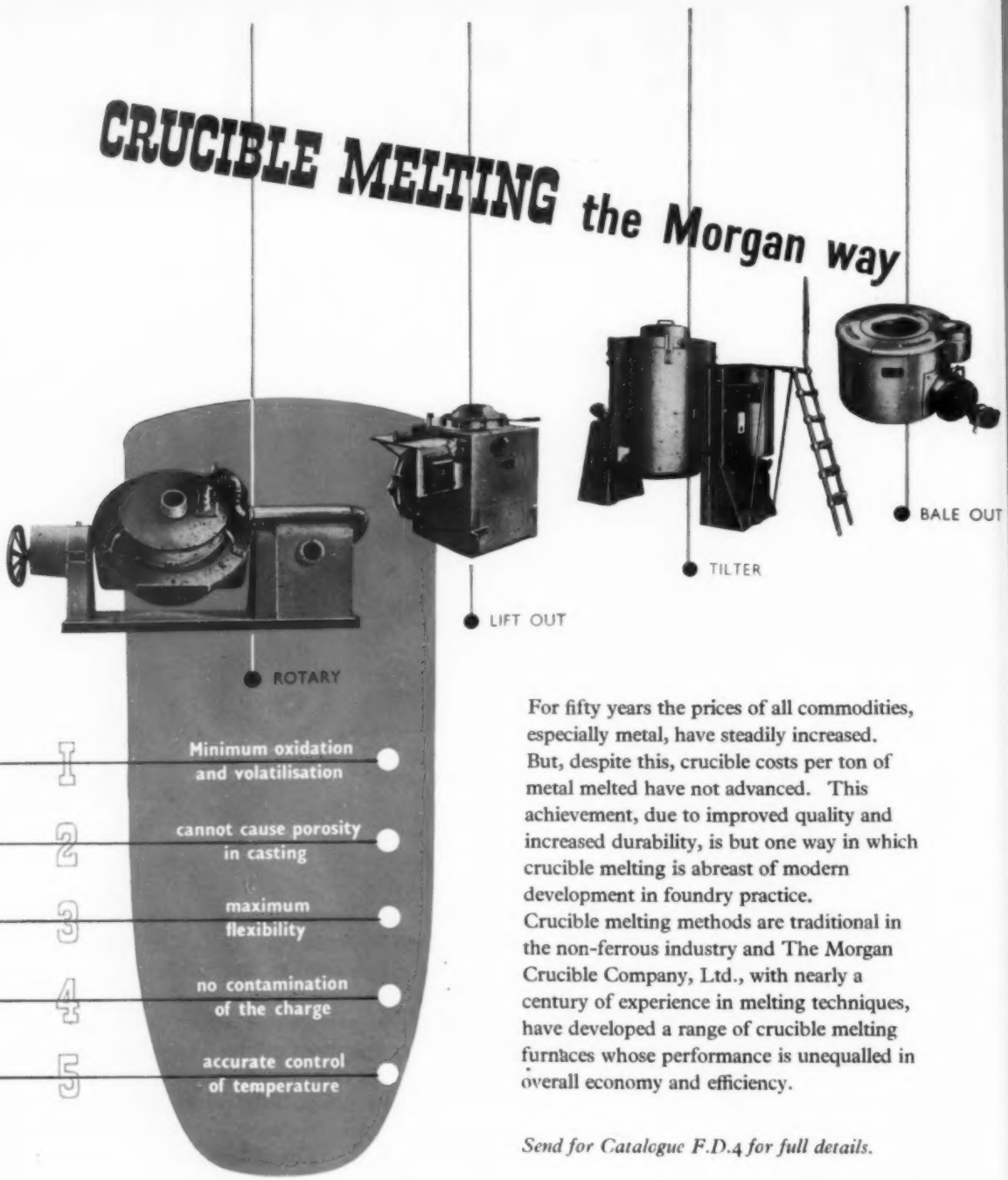

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F.8

Pig Iron — The Key to Expanding Steel Production

Now that the amount of scrap available to the British steel industry has fallen to more normal proportions, the ability to maintain, let alone expand, steel production will depend on our producing sufficient pig iron to feed the steel furnaces. Fortunately this situation was foreseen when the first development plan of the industry was put into operation and several new blast furnaces are now increasing appreciably the available capacity. The general position is outlined in this introductory article, and in the following pages more detailed consideration is given to a number of aspects of pig iron production.

SINCE the end of the war steel production has been aided by exceptionally large imports of scrap, mainly from Germany. This help was bound to be temporary, since part of the supply was due to war damage and an increasing quantity of the available tonnage was required for Germany's own use. Last year Britain's imports of scrap fell by nearly one and a half million tons, but steel production fell by less than half the amount that might have been expected from the drastic fall in imported scrap, mainly because some part of the increased supplies from previous years was still in stock ; it was possible to make good nearly half the deficiency last year by running down stocks of both pig iron and scrap. But the contribution of 600,000 tons from stock, which this country had last year, cannot be repeated. Indeed, to maintain steel production it is necessary first to replace the 600,000 tons of raw materials already drawn from stock, as adequate stock piles of raw materials are a vital element in stable production.

Therefore, apart from the continued effort which all steel-using and other industries will need to make to maintain, and if possible increase, the supply of home bought scrap, the main prospect of increasing steel production must rest on an expansion of pig iron production. It is fortunate that the long-term development plan in the iron and steel industry, which was approved in 1946, is already giving results in higher pig iron output. The production of pig iron in 1945, before the plan started, was seven million tons. Last year it had risen to nine and a half million tons. The objective for this year has been to increase pig iron production by an additional million tons to an all-time record level and to achieve, if possible, 10¾ million tons.

If this increase can be secured steel production, far from falling in 1952, will show a rise of about a quarter of a million tons over 1951—almost to the 16 million-ton mark. This output will be based neither on contributions from stock nor from large imports of scrap. It means that the stage is set for further advances in steel production as pig iron production can be still further increased.

The achievement of this substantial expansion in pig iron output of over one million tons this year is dependent entirely on the availability of iron ore and coke. Further increases in future years depend on these raw materials and also on the speed with which the blast furnace construction programme can be carried on.

Ore Supplies

The iron ore needed will be provided partly by a further considerable increase in the use of home ironstone. It is expected to use two million tons more home ore this year, but this needs to be supplemented by an increase of rather more than a million tons in the richer imported ore. Contracts are placed and shipping tonnage booked well ahead for a programme of this order of expansion. If Britain can do better still and increase imported ore by more than one million tons this year, its advance in pig iron production may be still greater than the essential minimum of one million tons.

To do this, the country will need substantial further additions to our ore supplies in subsequent years. A new ore development, undertaken in conjunction with the French at Conakry on the West Coast of Africa, is coming into operation at the end of this year. This should give at least a million tons of additional ore in 1953 ; it is capable, at fairly short notice, of expansion up to three million tons a year. The extent of the expansion depends largely on the degree to which this ore—which is not of the highest quality, though of relatively low cost—can be blended with other available ores in the blast furnace.

A possibly longer-term project, but one of greater ultimate importance, owing to the better quality of the ore which has been revealed by the preliminary exploratory work, is the Mauretania development. This involves constructing a railway line of some 300 miles into the Sahara, and a full-scale survey of the position is being undertaken this year—this time in conjunction with French and Canadian interests.

Coke Requirements

So far as this year is concerned the crucial factor in pig iron production is likely to be coke supplies. The greater part of the coke used by the steel industry is supplied from the industry's own ovens. Supplies from this source are going up in parallel with the increase in pig iron output, but there is a minimum, and fairly stable, quantity needed from outside sources, mainly the National Coal Board. This quantity is about 76,000 tons a week.

Looking further ahead, the expansion of pig iron output depends largely on the rate of construction of new blast furnaces. A substantial programme under the new development plan is under way, but furnaces are taking twice as long to build as before the war owing to the heavy load on the plant makers. The main bottleneck is the provision of boilers and blowers—and in both of these items the power station programme also makes heavy claims, due in large measure to the great expansion in the use of electricity since the war.

Britain should secure a steel production of about 250,000 tons more than in 1951 if a real emphasis is placed on pig iron output by the Government planning authorities.

The Production and Utilisation of Metallurgical Coke

By J. P. Graham, B.Sc., M.Inst.F.

Carbonisation Department, National Coal Board.

As there seems little likelihood of any revolutionary changes in our methods of making iron for many years to come, coke will continue to be required for this purpose. The quality of blast furnace coke is determined largely by the characteristics of the coal from which it is made, but, as the reserves of the best coking coal in Britain are limited, it will become increasingly necessary to conserve them by blending with lower rank coals.

MANY factors have played their part in the development of the coking industry in Great Britain, but the predominating influence throughout has been the need to provide the iron making industry with one of its primary raw materials.

The carbonisation of coal has developed, in little over a century, from a relatively simple craft to an extensive and highly technical industry[1] of vital importance in the national economy. In present times the need to meet in full the expanding demand for metallurgical coke is obvious, but certain features of the coke position involve considerations and problems which are difficult to resolve quickly, either for technical or economic reasons. It is of interest, therefore, to examine the coking industry in relation to the present metallurgical coke position, to consider the production of coke and the factors of importance in blast furnace coke utilisation, and to assess any trends which may manifest themselves in such a survey.

View of a new N.C.B. coking plant.

No specific mention will be made of foundry coke in this present article, although many of the factors considered in connection with coal supplies, production and quality are applicable to foundry coke as well as to coke for the blast furnace.

The Coking Industry in Great Britain

The primary object of the coking industry has always been to manufacture coke of a suitable quality for metallurgical purposes, the remaining products, that is to say the gas and the by-products, being of secondary importance. To this end, the modern by-product coking plant has been developed, and the industry has concentrated on the carbonisation of selected coking coal slacks which produce coke suitable, by reason of its hardness and size, for blast furnace and foundry practice. For economic reasons which will be mentioned later, there has been a growing need to show more interest in the "secondary" products but the main objective still remains the same.

The present scale of the industry may be judged from the fact that some 23·5 million tons of coal were carbonised in coke ovens in 1951 with the consequent production of 16·1 million tons of coke and 1 million tons of breeze, usually less than 1 in. in size. The disposal of this coke is shown in Table I, whilst the variations in production and disposals since the beginning of the second World War are shown in Table II.

TABLE I.—DISPOSALS OF OVEN COKE 1951
(excluding breeze)

Consumer	Percentage of Total Deliveries
Blast Furnaces	65·4%
Foundries	7·6%
Industrial	17·0%
Domestic	9·1%
Export	0·9%
Total	100·0%

In 1952 there were 4,664 by-product coke ovens in operation in Great Britain, distributed in 83 coking plants. These plants fall into three main categories so far as ownership is concerned. The National Coal Board own 51 coking plants; the iron and steel industry operates 23 plants, and independent companies own 9 plants. (The gas industry also operates 2 coking plants.) In general, the coking plants owned by the iron

1 Coke Oven Managers' Association. "The History of Coke Making and of the Coke Oven Managers' Association." (London, Heffer, 1936.)

TABLE II.—PRODUCTION AND DISPOSALS OF OVEN COKE IN THE UNITED KINGDOM * (tons × 10^6)
(excluding breeze)

	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951
PRODUCTION													
Coal Carbonised	20·4	22·0	21·1	21·6	20·9	20·1	20·1	20·0	19·8	22·3	22·6	22·6	23·5
Coke Produced	14·3	15·4	14·5	14·9	14·5	14·1	14·0	14·0	13·8	15·4	15·5	15·4	16·1
DELIVERIES													
Blast Furnaces	8·9	9·0	9·3	9·7	9·0	8·4	8·4	8·8	8·6	10·3	10·2	10·1	10·6
Foundries	0·9	1·0	1·0	1·0	1·0	1·0	0·8	0·9	1·1	1·1	1·1	1·1	1·2
Industrial	1·3	2·0	2·3	2·4	2·7	3·0	3·0	2·7	2·7	2·6	2·3	2·4	2·8
Domestic	1·6	1·8	1·8	1·6	1·4	1·7	1·6	1·4	1·5	1·1	1·0	1·2	1·5
Export	1·6	0·7	0·4	0·2	0·2	0·1	0·1	0·1	0·02	0·2	0·7	0·8	0·1

NOTE.—Difference between total deliveries and production is accounted for by stock figures at end of year.
* Figures from official Ministry of Fuel and Power annual returns.

and steel industry are individually larger units than those operated by the other two main groups as is evidenced from the figures given in Table III.

TABLE III.—COAL CARBONISED AND COKE PRODUCED IN 1951.

	Coal Carbonised		Coke Produced (excluding breeze)	
	Million tons	%	Million tons	%
Iron and Steel Industry Coking Plants	11·6	49·6	7·7	48·2
National Coal Board Coking Plants	9·3	39·8	6·6	41·2
Independent Coking Plants	2·5	10·6	1·7	10·6
Total	23·4	100·0	16·0	100·0

This general position, so far as size of plants is concerned, exists as a result of early appreciation by the old colliery owners of the significance of the development of the coke oven, and the first " modern " by-product coke oven batteries erected in this country from about 1880 onwards were located at collieries where they were able to absorb coking coal slacks which would otherwise have been difficult to utilise. At a later stage, iron and steel undertakings developed works which incorporated coke ovens of sufficient capacity to meet a large proportion of the coke requirements of their blast furnaces. From about 1925 onwards, the introduction of the silica coke oven, capable of more rapid carbonisation than the earlier semi-silica types, synchronised to some extent with the further expansion in the iron and steel industry when large modern coking plants were integrated with up-to-date iron and steel making plants. The significance of these events is apparent in the construction programmes which are being carried out in the coking industry at the present time.

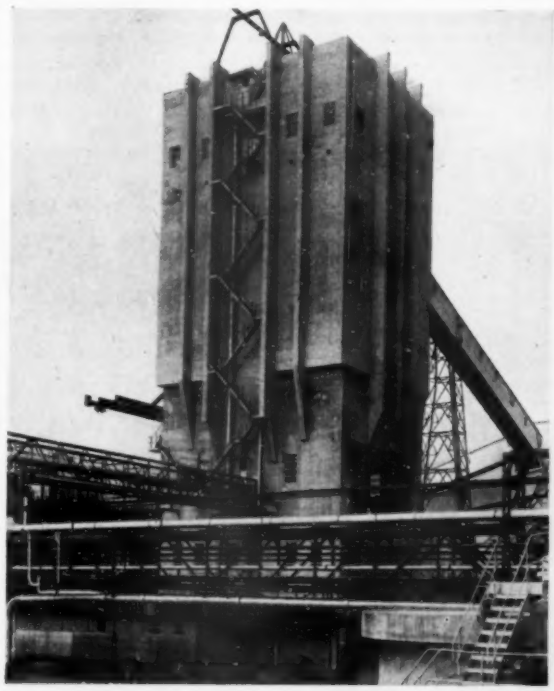
The programme of oven rebuilding and construction, actually in hand or planned for completion during the five or six year period ending in 1956, is of the order of £50 million. As indicated above, the coking plants acquired by the National Coal Board under the Coal Nationalisation Act in 1947 were, on the whole, older and smaller units than those operated by the iron and steel industry. The Coal Board's construction programme is devised to replace their coking capacity by larger centralised units in each of the major coke producing coalfields, and does not appear to give rise to any appreciable increase in the total carbonising capacity of the coal industry, at least over the next three or four years. The iron and steel industry on the other hand has a programme of construction of new batteries designed to raise the production capacity by something of the order of 2,000,000 tons of coke per annum during a similar period, and this expansion will go a long way towards meeting the increasing blast furnace requirements.

In any scheme for the erection of a new coking plant it is becoming increasingly important to give the most careful consideration to the economic conditions which will be applicable. The capital cost involved is now extremely high and a plant for the carbonisation of 1,000 tons of coal per day will cost something of the order of £2½ to £3 million. Gas is produced in very considerable quantities and there must be an adequate outlet for this gas if the operation of the plant is to prove economical. Such factors mean that it is no longer sufficient merely to consider the demand for the coke to be produced, and this must inevitably call for the most careful planning, particularly where the coke oven plant is not integrated with a large iron and steel undertaking.

Production of Metallurgical Coke

Modern coke ovens are generally built with dimensions approximating to :—

Length between doors	40 ft. (12,200 mm.).
Height, sole to crown	13 ft. (3,950 mm.).
Mean width	18 in. (450 mm.).



The main coal bunker for a coke oven battery.

They are tapered in order to facilitate discharge of the ovens and the extent of this taper is usually 2 to 3 in. (50 to 75 mm.). The ovens are erected in batteries, the number of ovens in a battery varying from 10 or 12 to as many as 60 or 80. The latest trend in construction in this country has been to erect ovens in relatively small blocks of not more than 25 ovens, in order to facilitate the rebuilding of the plant in sections when this becomes necessary. The ovens themselves are built with high quality refractory brickwork and are separated from one another by heating flues, so that each oven is heated simultaneously from both sides of the coal charge. The heating medium is either "rich" gas, that is coal gas produced in the process of carbonisation itself, or "lean" gas, that is producer gas or blast furnace gas. Whilst the process of carbonisation in an individual oven is a "batch" process, and therefore intermittent, the overall production from a battery of coke ovens is continuous, as the charging and discharging of the ovens is carried out to a predetermined schedule in order to ensure continuity of production.

Coal of suitable quality is charged into the top of the ovens from the hoppers of a charging car which runs along the top of the oven battery. Each oven on a modern coke oven plant has a capacity of some 20 tons of coal, and by employing suitable blending equipment on the coking plant it is possible to mix or blend various coals in defined proportions in order to obtain consistency of the blend to be carbonised.[2] This is of great significance as the quality of the coals charged is the most important factor influencing the quality of the coke produced.[3] The coal charged into the oven is crushed before carbonisation and usually has a size grading such that approximately 80% of the material will pass through an $\frac{1}{8}$-in. screen. At the end of a coking period lasting some 18 to 20 hours the doors at each end of the oven

2 British Coke Research Association, Panel No. 8. "Coal Blending for Carbonisation in Coke Ovens," Tech. Paper No. 4. (London, 1946).
3 British Coke Research Association, Panel No. 4. "The Study of Oven Dimensions in relation to Coal and Coke Quality," Interim Report to the Research Committee. (London, 1946.)

TABLE IV.
CLASSIFICATION OF COALS ACCORDING TO CAKING PROPERTIES.

Description	Volatile Matter Content (d.a.f.)	Gray King Assay Coke Type	Code Number
	%		
Anthracites	Less than 9·6	A	100
Low volatile steam coals	9·6–20·0	A—G8	200
"Coking" coals	20·1–30·0	G5 and over	301*
Very strongly caking coals	Greater than 30	G9 G10 and higher	400
Strongly caking coals ..	Greater than 30	G5—G8	500
Medium caking coals ..	Greater than 30	G1—G4	600
Weakly caking coals ..	Greater than 30	E—G	700
Very weakly caking coals	Greater than 30	C—D	800
Non-caking coals	Greater than 30	A—B	900

* Certain coals in the 20·1 to 30·0% volatile matter range (d.a.f.) which may have been subjected to igneous intrusion (i.e., which have been "heat altered") have a coke type A—G4 and are coded 300.

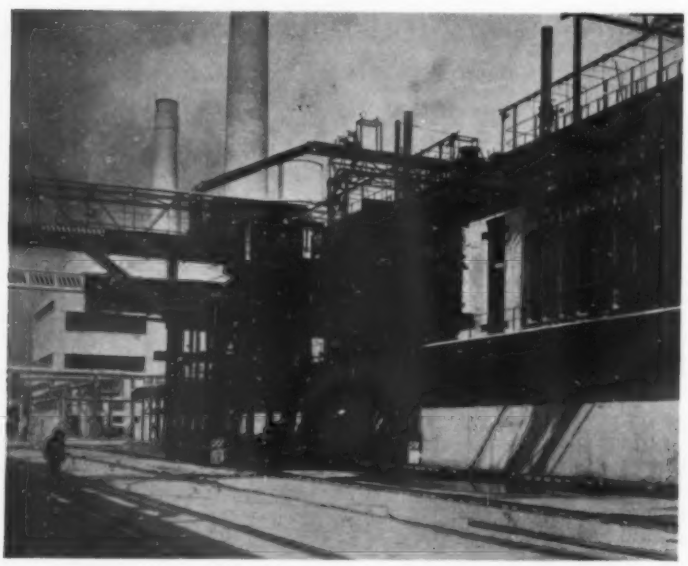
are removed and the hot coke is discharged from the oven into a coke car by means of a ram. The oven doors are then replaced, the oven recharged and the process repeated. The coke car is pushed (by an electric locomotive) under a quenching tower where a controlled quantity of water is sprayed on to the hot coke in order to cool it. The coke is then discharged on to a wharf from which it is removed by means of conveyor belts to the screening plant where sizing of the various grades takes place.

On heating coal, the volatile matter in the coal substance is driven off in the form of crude gas which is collected and treated in an extensive by-product plant, the primary by-products being tar, ammonia and benzol.

Importance of Coal Quality

Reference has already been made to the fact that the quality of the coal is the predominant factor governing the quality of the coke produced. The truth of this was demonstrated recently in an enquiry covering the major proportion of coking plants in Great Britain, which showed that over the range of British coals the rank of the coal is the most useful guide in predicting the quality of the coke to be obtained from any coking coal.[3] In order to appreciate the importance of this relationship in connection with the production of metallurgical coke, it is necessary to consider the methods of assessing the caking properties of a coal and the method of classification which has been adopted in Great Britain. The National Coal Board have now adopted officially the classification shown in Table IV which was first proposed by the Coal Survey[4] prior to the absorption of the Coal Survey within the National Coal Board organisation. The classification is based on the determination of the volatile matter content of the coal and on the results of the Gray King Assay.

Several laboratory tests have been devised for the assessment of the caking properties of a coal, and these have been published by the British Standards Institution.[5, 6] The final determination of the value of a coal from the point of view of coke production can only be made on a full scale trial, but much can be effected by the use of small



Ram side of coke oven battery.

4 Fuel Res. Survey Paper, No. 44. (London, H.M.S.O., 1940).
5 British Standards Institution. "British Standard Methods for Analysis and Testing of Coal and Coke," B.S. 1016. (London, 1942).
6 British Standards Institution. "British Standard Method for Determination of the Agglutinating Value of Coal, B.S. 705. (London, 1936).

scale test ovens which provide a guide to the performance of a coal or blend of coals in the coking plant.

The best metallurgical cokes are produced from the 301 coal which is found mainly in Durham or South Wales but which forms only 5·8% of the total reserves of coal in the United Kingdom. The approximate estimates of caking coal reserves[7] which it is intended to work during the next 100 years and which exist in seams of not less than 2 ft. thickness and lying at a depth of not greater than 4,000 ft. are given in Table V.

Anthracite and steam coals form 14·7% of the total reserves and high volatile very weakly or non-caking coals form the remaining 27·5%. Only the 301 and 401a group contain purely coking coals of medium volatile matter content. The 400, 500, 600 and 700 groups contain coal frequently carbonised either at coke ovens or at gas works, and occasionally the 800 and 900 groups may be used as constituents of blends for carbonising purposes.

One other factor of importance in this connection is that the relative outputs at the present time of each class of coal in the British coalfields indicates that all types of coal are being worked at a rate proportional to the developed reserves. This emphasises the point that there is a potential shortage of good coking coal and the growing need to concentrate on means such as blending for the conservation of existing reserves and for the greater use of the less strongly caking coal reserves.

Oven Developments

The coke oven as it exists to-day is an efficient industrial apparatus which has developed appreciably from the simple types of by-product recovery ovens first built in this country at the end of the 19th century. A clear step forward in construction took place about the late nineteen-twenties, when the use of high grade silica for oven building enabled faster carbonising rates to be employed. The average life of a silica coke oven battery in this country has been demonstrated to be from 15 to 25 years, so that it can be appreciated that many of the batteries have now come to the end of their useful life but must be maintained in operation until replacement capacity is available. The deterioration of coke oven batteries was aggravated by war conditions which delayed or prevented rebuilding or replacement. The construction of new coking plants takes something of the order of three to four years in these times of material shortages, so that the coking industry may be deemed to be passing through a critical phase. Furthermore, it is now desirable to expend appreciable capital upon blending facilities—bunkers, mechanical handling and coal crushers—in order to ensure that adequate attention is paid to the conservation of the diminishing reserves of coking coal, and to the achievement of consistency in the quality of the coke produced.

Red hot coke being discharged from ovens.

The principal changes which have taken place in oven design during the past fifteen or twenty years have centred round uniformity of distribution of the heat in the oven and improved regeneration of the waste heat.[7] The former consideration grew in importance with the increased size of ovens and the introduction of more rapid carbonising rates. Regenerator design has been developed to the point at which further increase in size would probably give difficulties due to condensation from the waste gases. The heating systems employed have also been improved in many respects during a similar period, and there has been widespread adoption of the underjet firing system which facilitates accuracy of control and improved operating conditions. The majority of ovens now being erected are of the "compound" type in which alternative heating by lean gas is possible, thus enabling a battery to release all its output of rich gas for sale or use external to the coking plant. This feature is of great importance in relation to town's gas supply in which coke oven gas has played an ever growing part in recent years.

Utilisation of Coke for Blast Furnaces

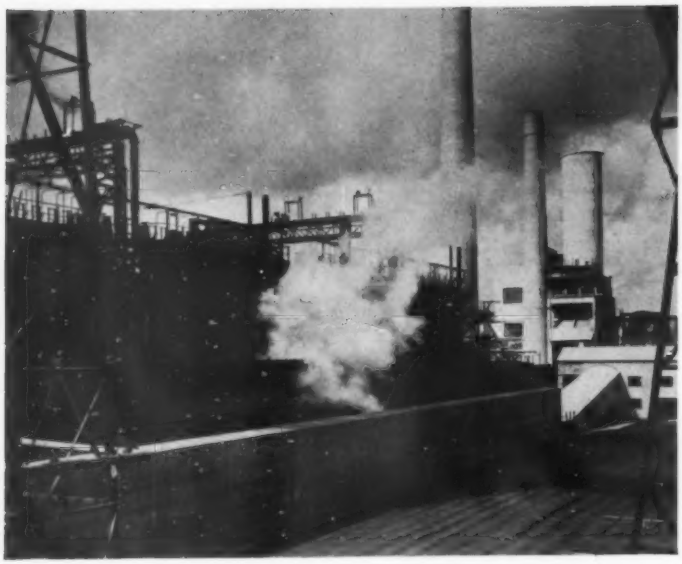
The present expansion in the iron and steel industry so far as coke production and furnace capacity are concerned, leads to the conclusion that blast furnace technique is unlikely to alter in any major respect for many years.[8] Coke oven plants now being built may be expected to last for 20 to 25 years. Heavy capital expenditure is being incurred to erect blast furnaces which will not be replaced to any appreciable extent by

7 Hicks, D., and Lee, G. W. Proc. U.N.E.S.C.O. Scientific Conf. on Conservation and Utilisation of Resources, New York, 1949, 2, 158–164.

TABLE V.—APPROXIMATE ESTIMATES OF CAKING COAL RESERVES TO BE WORKED DURING NEXT 100 YEARS.

Coal Rank Code Number	Developed Reserves (million tons)	Percentage of the Total Reserves
301 and 401a	1,556·2	7·6
400, 500 and 600 ..	7,402·3	36·1
700	2,894·4	14·1

8 Graham, J. P., Hall, G. E. and Lee, G. W. "Metallurgical Coke (Preparation—Properties—Utilisation)," 4th World Power Conf., London, 1950, sect. B.3, Paper No. 1.



Coke side of coke oven battery showing steam rising from quenched coke.

alternative processes for iron manufacture in the foreseeable future. Much attention has been paid to methods of securing even distribution of the burden and improvements have been made in this respect by careful preparation of the ore, the use of sintering and mechanical methods of distribution. On the other hand, efficient operation of the furnace still calls for adequate penetration of the blast through the burden, and for this reason the coke charged must meet certain requirements of size and quality which will withstand charging and support the weight of the burden. It is probable, therefore, that the physical properties of coke are of more importance in the blast furnace than are its chemical properties. Further, a coke of suitable chemical composition, but physically inferior, will not be satisfactory in the blast furnace, whereas a strong coke of poor chemical properties may be usable, because adjustment of operating techniques to take care of such items as sulphur content may be possible. Many opinions have been expressed as to the optimum size of coke for the blast furnace and it is, therefore, difficult to generalise, except in so far as it is accepted that fines must be eliminated. In addition, increasing thought is being devoted to the influence of consistency of size and size distribution.

A number of tests are now generally accepted in the iron and steel industry for the assessment of coke quality. Two main groups are involved, namely physical tests and chemical tests. The chemical tests are usually limited to proximate analysis, sulphur and phosphorus determinations. The problem of sulphur is being aggravated by the increasing scarcity of low sulphur coals employed for coke manufacture. The physical tests give rise to more controversy, and whilst the shatter and tumbler tests are probably the most important they are being studied currently with a view to modification and greater standardisation.[9]

In 1947, at a Conference sponsored by the Iron Making Division of the British Iron and Steel Research Association, that Association jointly considered with the British Coke Research Association, a statement on coke quality.[10] That statement was not established as an accepted measure of blast furnace coke quality, nor is it used as a specification for this country. It does give, however, an indication of the broad requirements of the iron and steel industry for the desirable properties of such coke. The main points of the statement were as follows :—

(1) *Size.* Coke smalls are of no value in blast furnace operation. Blast furnace coke should not be less than a size of the order of 1 inch, allowing a tolerance of 5% of coke less than the agreed size.

(2) *Moisture.* The moisture content of coke for blast furnaces must be low and uniform. Variations in moisture content should be avoided. The moisture content should not exceed 3%.

(3) *Ash Content.* The ash content must be uniform with a tolerance of 1%. The average ash content should not exceed 10%.

(4) *Strength.* Coke should be hard and should show at least 85% on the 1½ inch shatter test ; at the same time the ½ inch shatter index should not fall below 97%.

(5) *Sulphur.* It is stressed that the sulphur content of coke should be reduced as far as possible.

The difficulty of adopting a rigid standard of this type in Great Britain arises from the fact that the available quantities of coal of a quality which would produce coke of these characteristics are quite inadequate to meet the total demand. Added to this point, coke which might be suitable for one set of blast furnace operating conditions might be quite unsatisfactory for another plant, and it may safely be said that a universally accepted criterion for blast furnace coke is non-existent.

Future Trends and Conclusions

The view has already been expressed that the pattern of the methods of production of coke and iron in this country are unlikely to change materially for a period of at least 15 to 20 years, having regard to the construction programmes at present in hand and partially completed. There is also evidence to indicate that gross coke requirements per ton of pig iron produced will probably remain of the same order as they are at present, *i.e.* approximately 20 cwt. per ton of pig, although a small gradual reduction in the coming years is possible.[8] Thus the demand for blast furnace coke of a type at least similar to that now produced is liable to remain of equal magnitude for several years hence.

There are, however, several alternative processes for the manufacture of iron at present in operation, or being developed, of which mention should be made. Perhaps the more important of these are :—

(1) The low shaft oxygen furnace.

(2) The sponge iron process.

9 British Coking Industry Association, Council of Iron Producers and British Iron and Steel Federation, Joint Coke Consultative Committee. "Recommended methods for the sampling and determination of moisture in coke, at coke ovens and blast furnaces." (London, 1950.)

10 British Iron and Steel Research Association. "A Summary of the Proceedings at the Thirteenth Blast Furnace Conference held at Ashorne Hill, Leamington Spa, May 8th, 1947." (London, 1947.)

continued on page 82

The Iron Ore Position

A Survey of Current Developments

By a Special Contributor

The importance of adequate iron ore supplies to the production of the country's requirements of pig iron has already been stressed. Immediate and future prospects are discussed in the light of the criteria by which ore reserves are assessed—quality, accessibility and quantity.

IT has been pointed out—by Sir William Larke, among others—that more metals have been manufactured during the last half century than in all the hundreds of millions of recorded and prehistoric years that have gone before. Of this gigantic output, the bulk has been iron and steel, and in 1951 world steel production exceeded 200 million tons for the first time. All this has, in the last resort, been won in iron ore mines or quarries from the earth's crust. It is pertinent to ask about the prospects for the future; on a broad view, say covering the next couple of centuries, whether the world's riches of iron are becoming seriously depleted, and on a narrower view, how the situation is likely to affect the United Kingdom's iron and steel industry, and in particular the industry's plans for increasing pig iron production from 10½ million tons to 15 million tons a year during the next five years.

As far as the broader question of world supplies is concerned, three considerations apply to any possible developments; quality, accessibility and quantity. Clearly, judgments of these factors become increasingly lenient in times of shortage, and that must colour estimates of future conditions. This is perhaps most true of the first factor, quality. Already bedding, sintering, pelletizing and other beneficiation techniques make a practical possibility of lower grade ores than would, even a few years ago, have been considered economic. An example is the large deposit (perhaps 5,000 million tons) of high-silica, low-iron magnetic taconite in the Lake Superior region. Here jet piercing mining techniques and beneficiation by magnetic concentration and subsequent pelletising will soon make available 2½ million tons of ore yearly and possibly 10 million tons yearly in time.

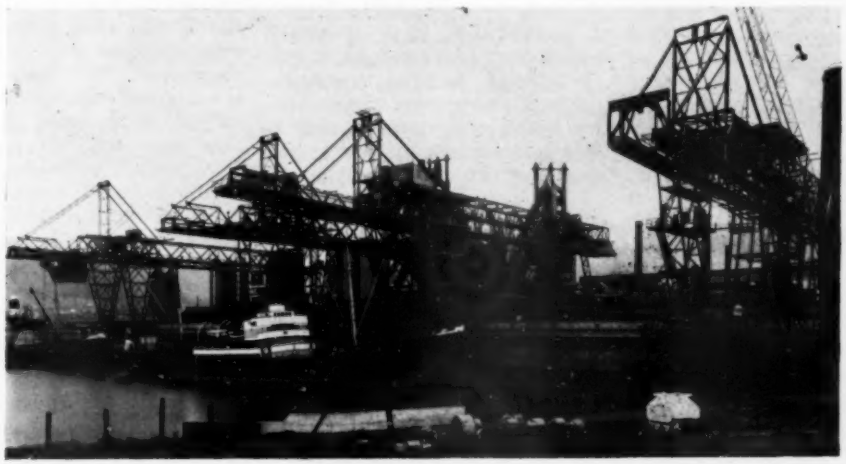
Nearer home, it is probably true to say that but for the bedding and sintering plants in Lincolnshire and Northamptonshire the exploitation of the sedimentary (Jurassic) ores would scarcely be economic (if it were possible at all) on any large scale. B.I.S.R.A., the United Steel Companies, Stewarts and Lloyds and Fords are all known to be working on these problems, in conjunction or separately, and it is already apparent that some of the most valuable developments may come from research on the design of sinter plants.

On the criterion of quality, then, it seems possible to say that modern techniques tend to make specifications for ore less rigorous.

Accessibility

Accessibility is also connected intimately with technical development, this time in transport. Efficient carrying and handling arrangements can offset the delay and inconvenience of bringing ore long distances. Margam, for example, now employs three high-duty unloading and stocking bridges, each with a nominal rating of 500 tons/hour. At Cleveland a modern installation has two transporter type unloaders rated at 350 tons/hour, and secondary berths equipped with cranes for "trimming" that part of the cargo that the unloaders cannot reach.

But the efficiency of any port installation is measured very simply by turn-round time, and here it is clear



Ore unloading wharf at the Margam plant of the Steel Company of Wales. The first of the three high-duty unloading and stocking bridges, each with a nominal rating of 500 tons per hour is seen in the centre, whilst on the right of the picture the second one is seen in course of erection.

A prospecting pit being sunk at Conakry.

that we in this country have still a very long way to go. According to the *Financial Times* (February 2nd, 1952), quoting the conclusions of a survey carried out by B.I.S.R.A., the turn-round of iron ore ships "could in many cases be cut from the present average of 5½ days to 2 days, or even less, for a typical 6,000-ton ore ship . . . if ports were suitably equipped and could be adequately manned for working three shifts instead of the single or double-shift systems operated at many ports." The design of ore—carrying ships is clearly of importance in this connection, and the *Financial Times* goes on to say: "Specially designed ore carriers now building should also help to cut turn-round time . . . six such carriers are now being built, to come into operation from July, 1953, onwards." Since then seven more ore carriers have been placed on order, with carrying capacities of 12,000 to 14,000. The earlier six are to have capacities of 8,000 tons, to keep them within the rather serious marine limitations of the Margam dock. For other docks, it is evident that 15,000 and 20,000 ton (capacity) ships will in the future offer considerable advantages.

Accessibility of another sort is that affected by extraction techniques. Mention has already been made of jet piercing, used for winning the Lake Superior taconites. The great new walking drag line at Corby is another case in point, where modern engineering techniques are brought to bear on previously insoluble problems.

On the criterion of accessibility, then, it would appear that transport facilities and dock arrangements at the receiving end can be improved to offset long hauls to some extent. Consequently, and because of advances in mining and quarrying techniques, attention can be paid to ores from fields whose exploitation would not have been considered economic even as recently as 20 years ago.

The last criterion, that of quantity, cannot really be divorced from accessibility. The capital costs of installing transport from remote fields and extraction machinery in nearer ones are astronomical. They are worth incurring only if they are likely to make large quantities of ore available. Two examples will suffice. The Labrador ore field, which is being opened up by United States and Canadian capital, involves the building of a 360-mile railway and a network of roads through wild country that it takes even a Red Indian a month to negotiate. The capital cost of the whole project is $200 million, but 400 million tons of ore at least are being made available. The other example is not so precisely documented as yet, but we are told that joint British, French and Canadian enterprise is considering the development of a source of ore in Mauretania, North Africa and that reserves of 100 million tons would be necessary to warrant the construction of a railway across 300 miles or more of desert and mountain. The capital that would be needed there is £20 million. (French, Canadian and British interests would provide it jointly in the proportions 51%, 34% and 15% respectively).

We can now look at the world picture of iron ore reserves, bearing in mind that modern techniques tend to make the iron industry more tolerant of low quality and long distances, but less tolerant of small deposits.

The World Picture

Over 90% of the world's iron ore supplies come from sedimentary deposits, both Pre-Cambrian and Post-Archaean. The former are high-grade ores, mainly over 60% iron, of which the Lake Superior ores are the most famous examples, having yielded over 2,500 million tons. Reserves of ore of this sort are given in Table I.*

The vast deposits in Brazil (Minas Geraes) and India (Bihar and Orissa) appear to be among some of the most important reserve resources in the world. In both cases transport difficulties discourage exploitation on a large scale. In Brazil, a rail haul of over 300 miles to the port of Victoria is difficult and expensive, and the ore is then still over 4,500 miles from the nearest U.S. plant. Venezuela is considerably nearer to the U.S.A. and the newly developed fields at Cerro Bolivar have already sent their first shipments there. Ten million tons per year from 1954 or 1955 are planned.

The Indian ores are already being shipped in small quantities to Japan and to Europe. The German industry in particular has expressed interest.

All the other deposits mentioned in the table are being exploited to a greater or less degree. The only one which seems to be suffering dangerous depletion is the Lake Superior reserve. Extraction here is rapidly reaching 100 million tons per year. Some of the measures being taken to replace these ores with taconites from the same region and with imports from Venezuela, Labrador and Liberia have already been touched on.

The main Post-Archaean sedimentary ore reserves are set out in Table II. All these beds are being exploited. The two deposits nearest home (U.K. and the Minette ores) should last 200 years at the present rate of extraction, even supposing no extensions are discovered. The biggest deposit, that of Newfoundland, is barely touched. Inevitably, extraction becomes more difficult as the easier deposits are worked out. It is at this point that the improvements in extraction and beneficiation technique mentioned previously in this article become relevant.

The picture given by the magnetite deposits is not dissimilar. The known Swedish reserves total some 2,000 million tons, against an annual extraction rate of 14 million tons. The known Norwegian deposits total 2,500 million tons, against an annual extraction rate of less than half a million. Chile extracts 3 million tons a year from 200 million with a possible further 200 million tons. There appears to be no imminent danger of depletion of any of the major deposits.

* "Monthly Statistical Bulletin" for September, 1951. Published by the British Iron and Steel Federation.

The "replacement" ore deposits of North Africa, the Urals and Utah are the remaining major source of the world's iron ore. Table III

The ore of Spanish Morocco is seen to be reaching depletion, just as the richer deposits of the ores of Bilbao in Spain have already been virtually worked out.

Immediate Prospects

In 1952 Great Britain plans to produce 16 million tons of steel, for which about 10½ million tons of pig iron are required. This marks the substantial achievement of the industry's first post-war development plan published in 1946. A second development plan is now being prepared, which has the object of raising steel production to 20 million ingot tons and pig iron production to 15 million tons per year. For 10½ million tons of pig iron in 1952 imports of 10 million tons of iron ore will be necessary, and extraction of 15 million tons of home ore. Table IV shows how these figures compare with previous years. It appears that the 1952 objectives will probably be reached. This reflects considerable credit on the industry's centralised ore-buying organisation, B.I.S.C. (Ore), Ltd., which was set up as a non-profit-making company after the war. The curves in Fig. 1 show how it has been necessary to change the pattern of our import trade to achieve this result. The increase of nearly one million tons of ore imports in the first six months of 1952, compared with the same period in 1951, is shared fairly evenly over the main sources of supply. The monthly averages for the first four months of 1952, for example, show an increase of about 57,000 tons/month from France and French North Africa and about 48,000 tons/month from Sweden. The increase from Commonwealth sources over this period was about 50,000 tons/month, of which that from Sierra Leone was 32,000 tons. Imports from Spanish North Africa increased by just over 1,000 tons/month, while those from Spain itself declined by about 5,000 tons/month.

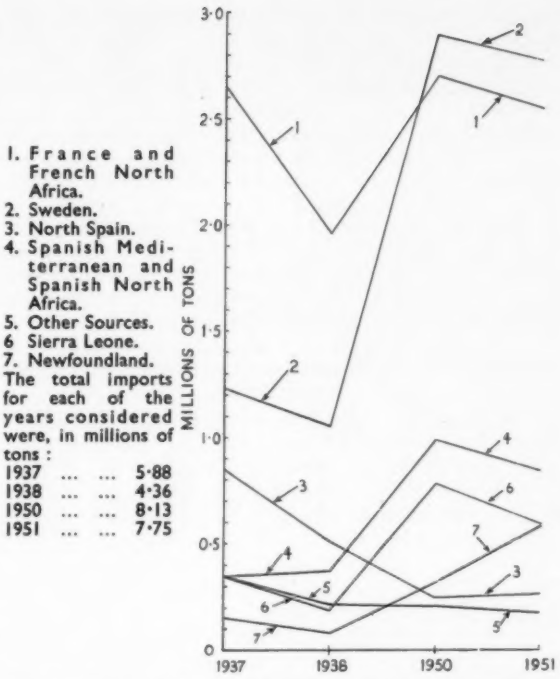


Fig. 1.—Sources of iron ore imports to the United Kingdom for the years 1937, 1938, 1950 and 1951.

TABLE I.—MAIN PRE-CAMBRIAN SEDIMENTARY ORE RESERVES

Region	Estimated Quantity
Brazil	13,000 million tons
India	10,000 " "
Lake Superior	1,200 " "
Labrador	2,000 " "
Venezuela	535 " "
Australia	1,100 " "
South Africa	700 " "
Krivoi Rog (U.S.S.R.)	2,300 " "
Manchuria	3,000 " "
China	600 " "

TABLE II.—MAIN POST-ARCHAEAN SEDIMENTARY ORE RESERVES

	Million Tons		Iron %	Phosphorus%	Remarks
	Estimated	Possible			
Newfoundland	3,000	—	48–57	0·7–2·0	—
Alabama	1,600	—	35	0·15–0·5	Clinton Ore
Tennessee and Georgia	82	15,000	35	0·15–0·5	Clinton Ore
France & Luxembourg	6,700	8,000	30–35	0·6–0·7	Minette Ore
Yorkshire to Northants	2,300	900	24–35	0·2–0·7	—
Salzgitter, Germany	1,000	—	29–33	0·3–1·0	—
Kerch, Crimea	1,650	1,080	38–43	0·45–1·0	—

TABLE III.—"REPLACEMENT" ORE DEPOSITS

	Reserves (Million Tons)	Iron %	Approximate Extraction Rate (Million Tons)
Algeria	300	44–51	2·5
Tunisia	90	51	0·7
French Morocco	125	45–52	0·4
Spanish Morocco	55	63–65	0·75
Urals	450	56–65	?
Utah	1,000	54	3·0 (?)

TABLE IV.—IMPORTS AND HOME ORE PRODUCTION IN RECENT YEARS

	1950 Actual	1951 Actual	1952 Planned	1st Six Months	
				1951	1952
Ore Imports	8,380,700	8,782,100	10,000,000	3,613,000	4,607,000
Home Production	12,936,000	14,647,000	15,000,000	7,220,000	7,913,000

By 1957 it is expected that this country will need to import 15½ million tons of ore yearly to keep pace with the second post-war development plan. Where are the extra five million tons to come from? From 1952 the United Kingdom is to increase imports by about 30%

from Newfoundland, bringing them to 1 million tons per year, an increase which will call for new mining, loading and shipping facilities, costing $6 million. Similarly, in Sierra Leone, development of mining and transport is in progress and an extra half million tons per year of concentrates may become available now that the technical problems connected with their utilisation appear to be on the way to solution. The Conakry ore field in French Guinea is being developed jointly by the French and ourselves and has deposits of 51·3% iron content estimated at 2,000 million tons. The first trial cargoes have arrived in this country, and the four-year development programme will achieve a production of 1·2 million tons a year in 1953. Developments in Mauretania, have been touched on earlier in this article. Should they materialise, they would begin to yield a tonnage of ore in about five years. Meanwhile Swedish production of iron ore is being stepped up, and exports of 14 million tons in 1951 reached a new record.

The situation is evidently not desperate, though there appears to be little margin of safety. Nor must it be forgotten that we are not the only pebbles on the beach. The German iron and steel industry plans a production of 16·5 million tons of steel in 1952, and has reached the point at which any increase in the tonnage of home ore used would increase the costs of steelmaking. Swedish ore exports to Germany are currently much less than pre-war exports (4·85 million tons in 1951, 8–9 million tons pre-war) and pressure to redress this may be expected, especially if Germany can produce an exportable surplus of coal and coke to pay with. Again, it was the bait of North African ores that may well have bought Germany's participation in the Schuman scheme. A German mission has already visited North Africa, a working party has been set up in Paris, and there have been reports of French and German agreements on investment in Morocco.

However, these developments are embryonic, whereas the work of B.I.S.C. (Ore), Ltd. seems to have placed Great Britain's ore economy on a firm basis. Generally speaking, and always with the reservation that much depends on the solution of dock and transport problems, there seem to be grounds for viewing the immediate ore situation in this country with cautious optimism.

The Production and Utilisation of Metallurgical Coke

continued from page 78

(3) The Krupp-Renn process.
(4) The electric pig iron furnace (Tysland-Hole processes).

These processes have been reviewed and described elsewhere in the technical literature, but they do not appear to be sufficiently serious competitors of the modern blast furnace in this country[7] greatly to influence the pattern prescribed by current plans, particularly as the following features must be taken into account.

(*a*) These alternatives are of limited capacity.
(*b*) The cost of electrical or other energy requirements is high.
(*c*) Tonnage oxygen is still relatively costly.
(*d*) The sponge iron process in particular requires a high quality of iron ore.

Certain other developments applicable to the conventional blast furnace, *e.g.* high top pressure techniques, may tend to accelerate the economies in coke consumption, but not seriously enough to alter the anticipated overall demand for coke in any appreciable degree. Thus the following broad conclusions may be reached from the information available :—

(*a*) The present blast furnace methods of manufacturing iron are likely to remain basically similar for a fair number of years ahead in this country, and thus coke will continue to be required in quantities similar to those now consumed in the iron and steel industry.
(*b*) The quality of blast furnace coke is determined very largely by the characteristics of the coal from which it is manufactured and, as the reserves of the best coking coal in Great Britain are limited, it will become increasingly necessary to conserve them by the use of lower rank coals and by extended use of coal blending.
(*c*) It is improbable that any single set of universally acceptable criteria for blast furnace coke quality could be established, and in any case, if any excessively high standards were set, then the supplies of suitable coals in this country would be inadequate to meet the total demand.
(*d*) It seems likely, therefore, that the expanding demand for blast furnace coke must be met in the future by the carbonisation of carefully blended coals giving cokes of consistent physical and chemical properties as development plans proceed. Achievement of consistency is probably one of the most important ways in which the coking industry can assist the blast furnace operator in the years ahead.

Acknowledgments

The writer gratefully acknowledges his indebtedness to the National Coal Board for permission to prepare this article.

Visits to Electric Furnace Works

DURING the winter each year Wild-Barfield Electric Furnaces, Ltd. are pleased to welcome parties of up to 30 senior engineering students from Technical Colleges and research establishments, to their Watford Works, where an interesting and extensive tour is arranged. The tour includes a visit to the production shops where electric furnaces from laboratory units to full scale production furnaces and induction heating equipment will be seen in all stages of manufacture. The metallurgical and chemical laboratories provide ample opportunity for the study of research methods and equipment, whilst the furnace development section affords the visitor scope for seeing many new heat-treatment processes and prototypes in the course of development.[8] An invitation is extended to visitors from September 1st. to May 31st, 1953, on any weekday afternoon (Monday to Friday) and early application is advised.

Co-operative Research in Iron Making

By K. E. Jermy, M.A. (Oxon.), A.I.M.

Technical Secretary of the Iron Making Division, B.I.S.R.A.

There are so many variables in blast furnace operation that the work involved in tracking down the effect of any one is a formidable task. Nevertheless, by fundamental work on furnace reactions, ore constitution, etc., coupled with works and pilot-scale trials on iron-making processes, the British Iron and Steel Research Association is making considerable progress towards a more complete understanding of blast furnace operation.

THE British Iron and Steel Research Association's part in present and future developments of the blast furnace side of the iron and steel industry is two-fold. First, there is the investigation and critical assessment of new features of plant and processes. Secondly, no less important, there is the dissemination throughout the industry of information concerning current practice and its developments, which is effected by staff liaison with member firms, reporting at Conference and Committee Meetings, and through published articles.

Work on the blast furnace burden and its preparation has had a considerable effect on the design of new plant approved under the British Iron and Steel Federation's Development Plans.

The size grading of the charge materials has a marked influence on furnace operation, and comparative trials were carried out to determine the most suitable combination of various types of primary and secondary crushers, which would give a desired degree of size reduction of ores at the least expense of undesirable fines production. At the same time, a wide range of home and foreign ores has been examined[1], to determine the optimum lump size of each for efficient chemical reduction in the furnace: this information has had considerable influence on crushing plant requirements at works where burden preparation schemes are being installed. B.I.S.R.A. also provided technical assistance at the works assessments in 1949 of the first three consignments of ore from the deposits at Conakry, in French Guinea, which are now being developed for full-scale export to the U.K.

The efficient utilisation of home ore fines, which becomes of increasing importance as home ironstone production expands, has been materially assisted by the full-scale plant trials, extended over four years, which determined the effects of carbon content, ore and coke size, mixing of raw materials, and other factors in producing sinter of a high quality[2].

1 Wild, R., and Saunders, H. L. The Reduction of Lump Ores. *Jnl. Iron and Steel Inst.*, 1950, **165**, 198.
2 Gillings, D. W., Voice, E. W., Lang, C., and Gledhill, P. K. The Sintering of Northamptonshire Iron Ore: a Production Plant Study of Factors Affecting Sinter Quality. *Jnl. Iron and Steel Inst.*, 1951, **167**, 400.

The Organisation of Co-operative Research in Iron Making

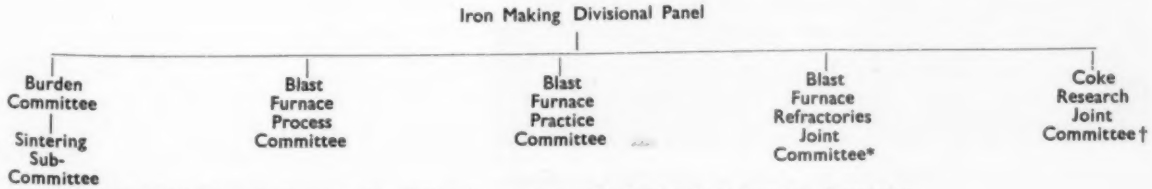
The Iron Making Division[3] is one of the five divisions of B.I.S.R.A., engaged on problems which are of importance to the whole industry, or which cannot be feasibly approached by individual firms. The field of investigation is wide, covering all processes of iron production from the raw materials to hot iron in the ladle, or to cold pig-iron.

Research is supervised at all stages by Research Committees, drawn from managerial and technical staffs in the industry, and representatives of academic institutions engaged on similar problems. Overall supervision is exercised by the Iron Making Divisional Panel, which is also responsible for the allocation of the Divisional finances and research effort between its many projects; the present Panel Chairman is Mr. W. C. Bell, Director of Research and Technical Development (Iron and Steel) of Messrs. Stewarts and Lloyds, Limited. The accompanying table gives a schematic diagram of the Committee structure.

The scientific staff numbers thirty, under the leadership of the head of the Division, Dr. H. L. Saunders. Head Office and the Blast Furnace Reactions Laboratory are in London: fundamental work on furnace reactions, ore constitution etc. are carried out here. In 1950 the North East Coast Laboratory was established at Normanby, near Middlesbrough: this site provides access to the great iron-producing areas of Tees-side, North Lincolnshire and Durham. Working facilities at the nearby Redcar Works have been provided by Messrs. Dorman Long & Co. Ltd., and most of the works and pilot-scale trials on iron-making processes are organised from Normanby.

The Division maintains close liaison with work on ores and sinters at London University and the Royal Technical College, Glasgow, and with the activities of the British Ceramic Research Association and the British Coke Research Association, insofar as they concern blast furnaces.

3 Annual Report of Council, 1951. British Iron and Steel Research Association.



* Joint with British Ceramic Research Association. † Joint with British Coke Research Association.

An important aspect of the Division's centralised work is the organisation of one or more Blast Furnace Conferences per year, at which plant operators and scientific workers discuss their problems at a common forum. Another popular annual event is the Junior Blast Furnace Conference, where assistant managers, foremen and trainees gather for informal discussions.

In the following paragraphs, several of the Division's more important items of work are described, but space forbids the mention of many applied or laboratory projects which are in hand.

Direct Work on Blast Furnace Operation and Design

Much valuable work on blast furnace problems has been done in the laboratory and on small-scale plant: it is noteworthy that an experimental blast furnace (hearth diameter 21 inches) was operated for several years by B.I.S.R.A. at the works of the Shelton Iron, Steel and Coal Co. Ltd., and results concerning the effect of controlled radial distribution of the charge have been published[4].

Nevertheless, the full-scale furnace itself remains the final arbiter of any changes in process, and the need for a co-ordinated programme of full-scale trials has recently become very apparent. It is also true to say that much still remains to be learnt of the chemical reactions and physical conditions obtaining at various zones of the furnace, due to the difficulties of access to the interior of the furnace, its massive size, and the length of its campaigns (up to 10 years). Consequently, a programme of full-scale trials has been formulated for an operating furnace: these are designed to investigate quantitatively the effects on furnace operation of (*a*) changes in size grading of ore and coke, (*b*) changes in burden constituents, and (*c*) changes in charge distribution. To be successful and significant, such trials should be carried out with all operating variables held constant except the one under examination. Results obtained will be of great value in the compilation of an acceptable index of blast-furnace performance, applicable to the diverse range of burdening and operating conditions found in British practice; this problem has been examined for several years by statistical and empirical analysis of collected operating data, but has proved extremely complex.

Messrs. Dorman, Long & Co. Ltd., have kindly agreed to the use of their two identical 18-foot hearth furnaces at Redcar for trials, whenever production conditions allow. Several periods of test have been made and it soon became apparent that results would be of questionable value until the response of the furnace to variations in wind blown, in terms of coke rate and iron output, was known quantitatively—in effect the "calibration of the furnace." Determination of these "response curves" has been commenced, but work has lately been held up by the prevailing uncertainty of ore supplies, and the need to produce maximum iron outputs for the steel furnaces as a result of reduced scrap availability. The need for resumption of this work, however, is a prime consideration, and means of accelerating this are being explored: in the meantime, every opportunity is taken of obtaining new information from operating furnaces, through exploration techniques described below.

A project which promises to be of great value in prolonging furnace life concerns hearth design. Carbon is used as the hearth refractory in many modern furnaces, and it is common experience to find that the central portion of the hearth has disappeared after a campaign, although carbon side-walls have generally proved their worth in remaining stable and preventing break-outs of iron. This fact has focussed attention on the flow of heat through hearth refractories. The mathematical technique of "relaxation" is available to explore the problems, but this is tedious and time-consuming: consequently, B.I.S.R.A. Physics Department has collaborated in constructing electrical and thermal analogues to investigate hearth design. The electrical analogue is shown in Fig. 1; essentially it is a network of variable resistances which can be adjusted to conform with known designs of any hearth and its foundations, The flow of electricity through the network is analogous with the flow of heat through the hearth, and hence temperature distribution can be predicted. The thermal analogue is a scale model of an actual furnace hearth: in this, actual temperatures are measured, the scale effect giving readings after a few hours which correspond with years in the life of the actual furnace. Results from the analogues are checked against readings from thermocouples installed below the hearths of several operating furnaces. Preliminary results[5] indicate that failure of carbon hearths is attributable to the high thermal conductivity of carbon, which allows molten iron to exist at a greater depth than in firebrick hearths; the central carbon blocks may therefore become surrounded by liquid iron, and hence subjected to considerable up-thrust which causes flotation. B.I.S.R.A. is strongly recommending cooling under the hearth (which can be achieved by air drawn through pipes at low power requirement) and/or deeper carbon blocks to extend below the

4 Saunders, H. L., Butler, G. B., and Tweedy, J. M. Investigations on an Experimental Blast Furnace. *Jnl. Iron and Steel Inst.*, 1949, **163**, 173.

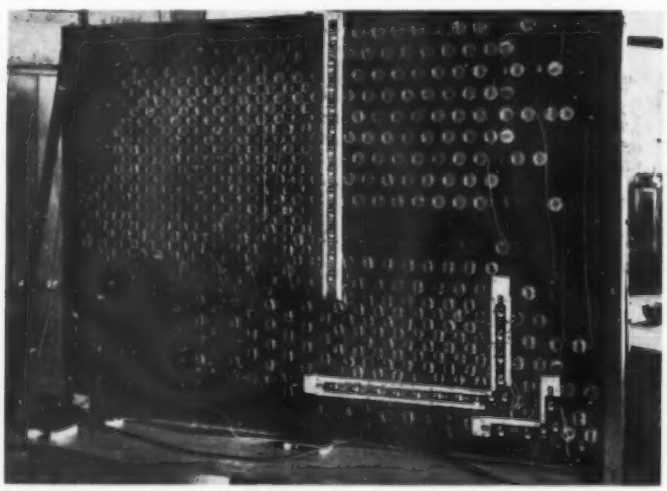


Fig. 1.—Electrical analogue for the study of heat flow in blast-furnace hearths.

5 Voice, E. W. Carbon Hearths for Blast Furnaces. *Iron and Coal Trades Review*, 1953, **164**, 1265.

"freeze line." Under-hearth cooling can also reduce the danger to concrete foundations by over-heating due to the high conductivity of carbon. It is illogical that the central hearth pad should be the only part of the lining which is not cooled in any way; and air cooling has now been incorporated in one design for a new furnace.

In recent years, the Division has developed several useful techniques for exploring furnace conditions without interrupting daily production. The detection of radio-activity from radon released in the blast has given values of the gas transit times[6] as well as showing whether furnaces are driving more actively near the walls or the centre. The radio-active isotope Cobalt 60, produced by irradiation at Harwell, can be embodied as pellets at various positions in the furnace lining: the disappearance of radio-activity indicates that refractory wear has occurred.[7] Active Cobalt has also been used to determine burden transit times, and to estimate the volume of the "sump" of molten iron in the hearth. The so-called "fishing-rod" is a mechanical device[8] for determining stockline contours and rates of descent at all radial points, which provides fuller information than the conventional stock-rod indicator. Work is now in progress, assisted by the Physics Department, on two optical techniques: one is a periscope which can be lowered through a stock-rod hole for inspection of the furnace throat and armouring bars. Another is steroscopic photography through the tuyeres[9]; briefly, two simultaneous series of high-speed cine photographs are taken through special tuyere attachments, then viewed through a polaroid system (as used at the Tele-Kinema) to give a stereoscopic view of the coke and other particles present in the combustion zone. Analysis of the films is providing information on the size grading and velocities of the coke particles, and the shape of the tuyere combustion zone.

Treatment of Iron Ores

The iron-bearing constituents of the burden are generally receiving increasing attention, both as regards optimum size and the utilisation of all available sources of iron units. British ores are low in iron (average 30% Fe) and the melting of the associated gangue imposes a heavy load on the furnaces. B.I.S.R.A. has commenced work on methods of beneficiation of ores, particularly the lean ores of Northamptonshire and Oxfordshire. This is necessarily a long term project, involving much petrographic and microscopic examination, but it has been greatly assisted by the development of micro-radiography for particular application to iron ores and sinters[10]. The technique obviates many errors in identification of minerals and estimates of iron content inherent in conventional photo-micrography.

Fig. 2.—Pilot plant for the pelletizing of fine iron ore.

An interesting ore problem is the development of a pelletizing process: this has arisen from the present industrial need for the best utilisation of all available iron-bearing materials. Certain types of very fine ore and residues bring about marked reductions in output when sintered conventionally for blast-furnace use; consequently, B.I.S.R.A. has been asked to investigate the possibilities of a pelletizing process. A pilot plant has been erected at Redcar Works (see Fig. 2) and pellets of ¼–2 in. size, with adequate strength for a furnace feed, have been made. The essentials of the process are :—(*a*) a sufficiently fine initial material (50% –200 mesh seems preferable), (*b*) "balling up" the fine powder with water and a binding agent to produce a handleable "green" pellet, and (*c*) firing in a kiln to produce a strong final product: temperatures required vary with the ores used, but 1300°C. has been adopted for hematites. Results are promising and the present stage of the work consists of exploring (*a*) grinding methods to find the most economical way of producing the initial powder, (*b*) mixtures of ores which may pelletize without needing such drastic size reduction, (*c*) suitable materials handling methods, and (*d*) improved firing. Parallel investigations are being pursued in conjunction with firms in the industry, with a view to increasing sinter outputs from very fine ores.

Initial work on improving sinter outputs on normal burdens by the United Steel Cos. Ltd.,[11] has been followed by intensive trials by B.I.S.R.A. on industrial plants and on the experimental sinter box at Redcar (see Fig. 3). The box is a 2-foot square section of a sinter pallet, with ignition hood and suction fan: it operates as a "section," as opposed to a model, and results from it correlate well with those from full-scale sinter plants[12]. Earlier B.I.S.R.A. work [2,12] had concentrated on sinter quality, but the latest investigations have provided a new explanation of the mechanism of sintering in terms of permeability of the bed, leading to

6 Voice, E. W. Furnace Exploration. Radioactive Technique for Determining Gas Transit Times in a Driving Blast Furnace. *Jnl. Iron and Steel Inst.*, 1949, **163**, 312.
7 Voice, E. W. Radioactive Tracers for Blast Furnace Refractory Wear. *Jnl. Iron and Steel Inst.*, 1951, **167**, 157.
8 Voice, E. W. The Measurement of Stockline Contours on Driving Blast Furnaces. *Jnl. Iron and Steel Inst.*, 1950, **166**, 84.
9 Ward, H. D. Discussion at the 1951 Annual General Meeting. *Jnl. Iron and Steel Inst.*, 1952, **170**, 131.
10 Cohen, E. Micro-radiography applied to the Study of Iron Ores and Sinters. *Metallurgia*, 1950, **41**, 227.
11 Voice, E. W., Brooks, S. H., and Gledhill, P. K. (To be published).
12 Voice, E. W., Lang, C., and Gledhill, P. K. Investigation of Controlled Variables on Sinter Quality: Part I—Development of Experimental Sinter Plant and Results Using Northants Ore. *Jnl. Iron and Steel Inst.*, 1951, **167**, 393.

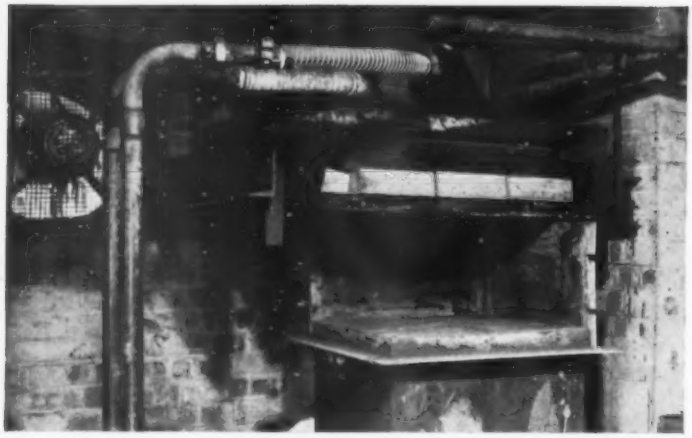


Fig. 3.—Sinter box for experiments on the mechanism of sintering iron ore fines.

formulae which provide quantitative estimates of the effects of process variables on sinter output, time to sinter, suction requirements and horse-power. This information, which points the way to increased output, will have considerable importance in future sinter plant design, and also in the design of sinter cooling systems, where similar permeability considerations apply.

Recent results from the sinter box have indicated that, with certain foreign ore mixes, addition of a few per cent of powdered lime can have a substantial effect in reducing sintering time, hence providing a means for further output increases. Works trials have confirmed these results, and a further series of full-scale plant trials has been planned.

External Desulphurization of Iron

The removal of sulphur from iron in the blast furnace imposes a considerable load in carrying sufficient lime in the slag: if this need were reduced, slag volume, and hence coke rate, could be reduced. Laboratory investigations[13] have shown that lime lumps, fired to 1200°C., can effect a fairly rapid desulphurization of pig iron outside the furnace. Only the surface layers are concerned in the reaction, and estimates have been made of the lime surface needed to achieve any given degree of sulphur removal. It has been proposed that a method using lime-coated lumps of coke be adopted: this would economise in both lime and coke (the latter being washed and re-coated for further use), and would further permit the collection of a slurry from which scarce sulphur could be recovered. This work has reached the stage of small-scale trials with pig-iron on a blast furnace plant.

Research into Blast Furnace Refractories

Since 1930 joint research has been carried out for the iron industry by the British Ceramic Research Association, mainly on the basis of the examination of furnace linings after blowing-out, with supporting laboratory work. A wealth of valuable information on the behaviour and failure of refractories has been collected with emphasis on failure by carbon deposition catalysed by iron spots, and scaffold formation[14]. This research has proved a stimulus to the adoption of novel refractory materials in the stack, *viz*: carbon[15] and china-clay: in the latter, carbon deposition is largely eliminated by the low, well-dispersed iron content. For any refractory, high firing temperatures will minimise the spread of carbon deposition by ensuring chemical combination of iron minerals and increasing the structure density of the brick.

Recent investigations have shown that the lifting from the foundations experienced with several ferro-manganese furnaces can be explained by the ready oxidation of ferro-manganese in impregnated bricks, causing severe dimensional distortion: this emphasises the need to prevent the infiltration of air or moisture below the hearth. The same occurrence with carbon hearths may produce oxidation of the edges of carbon bricks, and thus be a contributory factor in the failure of the central portions of many carbon hearths.

Low-shaft Furnace Research

The possibility of using low-shaft furnaces as adjuncts to blast-furnaces on ironworks has been suggested: in these, some small or low-grade ores and cokes might be smelted directly, instead of requiring sintering or other disposal as at present. This problem is more pressing on the Continent, where considerable amounts of low-grade ores and fuels are available, and an international research project[16] was promoted by O.E.E.C.; B.I.S.R.A. represents the British industry on the technical committee. A low-shaft furnace is under construction in Belgium, and the experimental programme will include the determination of the minimum sizes of ore and coke which can be smelted together without briquetting, high top pressure, oxygen-enriched blast, and briquettes made from ore fines, low-grade cokes, and other fuels.

Conclusions

The field of blast furnace practice and processes, burdens and sinter, coke and refractories, presents many problems, which will engage research workers for many years to come.

A number of current projects have not received mention here, but the items reported will show how B.I.S.R.A. work is concentrating on technical efficiency in terms of increased outputs and fuel economy. Output is currently receiving emphasis, to meet industry's need. A very satisfactory and noteworthy feature of the present state of research in iron-making is the free co-operation with B.I.S.R.A. work which is afforded by the individual firms in the industry, in the ways of providing opportunities for works trials whenever production needs allow, supplying operating data, and exchange of opinion at all levels.

13 Gledroyc, V., and Dancy, T. E. Desulphurization of Pig Iron by Solid Lime. *Jnl. Iron and Steel Inst.*, 1951, **169**, 353.

14 Rigby, G. R. Investigations Relating to Scaffolds in Blast Furnaces. *Jnl. Iron and Steel Inst.*, 1949, **161**, 295.

15 Chesters, J. H., Elliot, G. D., and Mackenzie, J. The Evolution of the All-Carbon Blast Furnace. *Jnl. Iron and Steel Inst.*, 1951, **167**, 273.

16 Dancy, T. E. The Low-Shaft Blast-Furnace International Project. *Coke and Gas*, 1952, **14**, January, 22.

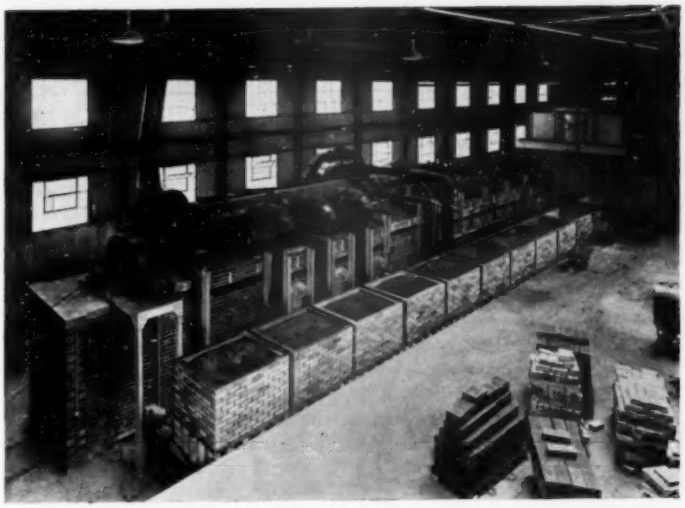
Carbon Refractories Manufacture

New Tunnel Kiln in Service at Loxley

THE lighting-up recently of the new tunnel kiln at the Loxley Works of Carblox. Ltd., represented the culminating point of an expansion scheme that has been taking place over the last two years. A few short years ago, two companies associated in order to study and manufacture carbon refractories, at the request of the iron-making industry. These two companies were Thomas Marshall & Co. (Loxley), Ltd., of Loxley, Sheffield, and The Morgan Crucible Co., Ltd., of London, and the Company so formed was Carblox, Ltd., of Storrs Bridge, Sheffield. Thomas Marshall's brought with them over 100 years' experience in the manufacture of refractories, and The Morgan Crucible Co., Ltd., a similar wealth of knowledge in the handling and manufacture of carbon. Together they investigated, developed and produced Carblox Refractories. Within a very short space of time, so successful was this product, that it became apparent that the demand, both home and overseas, for this type of refractory was far outstripping the capacity of the original pilot plant. With improved manufacturing methods and technique it was possible to increase output. Thus, within three years of commencing full scale manufacture, Carblox had more than doubled their output and have continued to increase their production every year. Even these efforts did not solve the ever-growing problem of supply and demand, and it was obvious that new plant would have to be erected. The Board of Carblox, Ltd., put in hand a programme of expansion involving the erection of new buildings and plant ultimately to quadruple the 1950 output. The starting-up of the tunnel kiln, already mentioned, represented the end of this second phase of Carblox history—a phase which it is anticipated will meet all the demands of the iron and chemical industries for many years to come.

The new tunnel kiln is worthy of note, and the following details will be of interest. The overall dimensions are 133 ft. long and 18 ft. wide, 12 ft. high, and it has a capacity of 23 cars which are 5 ft. 6 in. long, 5 ft. 3 in. wide. The cars are fitted with built-on containers which each hold approximately 3,500 lb. of Carblox carbon products and packing. The car schedule is one car per two hours, giving a total output of 100/140 tons per week, according to the type of material produced.

The kiln is of a special design and is capable of dealing with the volatiles given off from the green ware without resorting to any extra kilning space. This design enables a short operating cycle to be employed and appreciably steps up production. Automatic temperature control ensures suitable conditions throughout, maintained to limits of ± 10° C. Fourteen temperature recording points throughout the length of the kiln are connected to potentiometric recorders and controllers of the latest design.



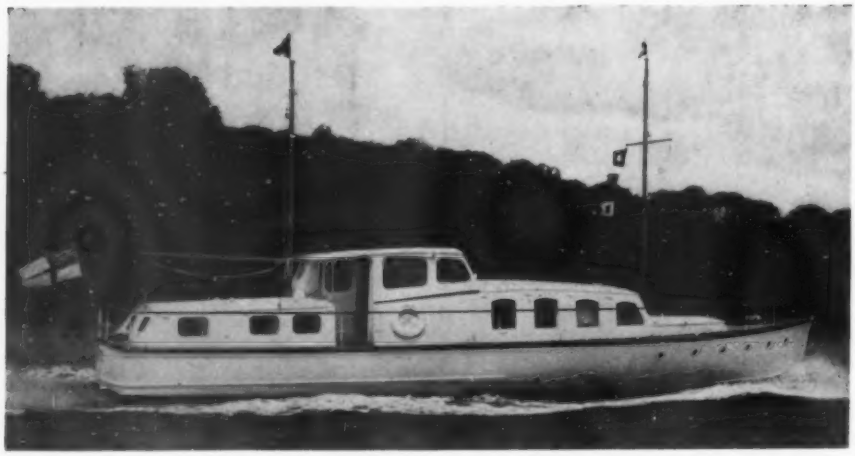
End view of new tunnel kiln showing cars with built-on containers in the foreground.

The firing system is unique in that it has been designed primarily for oil-firing, using heavy fuel oil, but provision has also been made within the kiln structure to use part, or all, of the volatiles given off by the charge as an additional heating medium. The controls mentioned above operate the oil fuel valves to give the correct firing temperature. Another interesting feature of the kiln is that there is no large brick-built stack. The control of the exhaust is effected by a venturi system which obviates the necessity for a large brick structure.

The kiln will be used for the production of all forms of carbon refractories, and will play an important part in increasing the already appreciable export business of this Company. It is worthy of note that, in addition to supplying the demands of the industry in the United Kingdom, Loxley distributes these products to such widely separated places as Norway, Sweden, Finland, Portugal, Holland, Belgium, France, South Africa and Australia.

New Metalock Branch

To speed up still more their cold repair service, Metalock have recently opened an office in Liverpool at 33, The Temple, 24, Dale Street (Telephone : Liverpool Central 3820). The area manager is Mr. A. Tinwell. Originally all Metalock operators were despatched from the London headquarters, but their presence at the ports is particularly useful in facilitating the quick turn-round of shipping. British depots are now established in Newcastle, Glasgow, Grimsby, Coventry, Cardiff and Port Reath, Cornwall, (Telephone : Port Reath 228—Mr. Scott).



Light Alloy Luxury Yacht Built on Two-Way Tension System

THE 60-ft. M.Y. *Tonquin*, Royal Yacht Squadron, designed and built by Messrs. Grimston Astor, Ltd., is the largest all aluminium yacht ever launched in this country and is built to the requirements of and under the supervision of the Ministry of Transport from aluminium alloy supplied by the British Aluminium Co., Ltd. Her superior speed and manoeuvrability combined with economy of running and maintenance costs demonstrate the advantages of the "Two-Way Tension" system of construction in which Grimston Astor specialise.

This method of construction employs the stressed skin technique in a manner somewhat akin to that now commonly utilised in aircraft design. The light alloy sheets forming the skin of the vessel are shaped and joined in the flat state and the transverse members attached. The sides are then pulled up into shape, creating a condition whereby a springy resilience is imparted to the skin by reason of the acquired strain energy which is retained in the structure. Thus, in this case, sheet of 10 s.w.g. has been used successfully to form the skin of a 60-ft. hull.

The design of the hull is based on the survey vessel *Ain-Al-Bahr* which the Company built last year to the order of the Pakistan Government for river survey work. Before being delivered this craft had demonstrated to numerous leading naval architects and representatives of British and foreign government departments, during many weeks of exhaustive trials, her ability to achieve more than 13 knots using half the power and fuel required by a contemporary teak-built vessel of the same size built in Pakistan to fulfil similar requirements.

Whereas the accommodation specified for the *Ain-Ae-Bahr* was austere, M.Y. *Tonquin* has been fitted out to give the highest standard of finish and comfort which would appeal to the most fastidious of prospective owners. The overall impression that *Tonquin's* accommodation gives is one of spaciousness and comfort far in excess of many a larger conventionally built yacht. Despite the fact that no sacrifice has been made in the accommodation or equipment to conserve weight, the cruising speed of *Tonquin* compares more than favourably with the most modern of post-war motor yachts.

Tonquin is very manoeuvrable, being able to turn in less than two lengths at full speed, and maintains her cruising speed of 12 knots using less than 10 gallons per hour, giving a consumption of 1·2 nautical miles per gallon. Her light alloy construction ensures exceptionally low maintenance costs particularly since her weight is only 14 tons (approx.) and it has, therefore, been a simple matter to arrange twin keels enabling her to take the ground in a level position, thus eliminating many slipping expenses.

The material used for the plating of the hull is 10 s.w.g. aluminium alloy quarter hard to specification N.S.5 by The British Aluminium Co., Ltd., who also supplied the 5 in. × 1$\frac{7}{8}$ in. × $\frac{3}{4}$ in. × $\frac{3}{8}$ in. tee section alloy to specification N.E.5 for the keels, whilst stern castings by Victor Moyle & Co., Ltd., and skegs by Northern Aluminium Co., Ltd., are in solution treated aluminium alloy to specification L.M.10.W. The propellers—light alloy 17 in. × 14 in.—and chromium plated shaft were made by Parsons Engineering Co., Ltd., of Southampton.

The vessel has been built to the order of Mr. John Astor, a Director of Grimston Astor and shows how the Company's "Two-Way Tension" system of construction can benefit yacht owners by virtue of low running costs at an initial cost which is competitive. She has been constructed and fitted to the highest possible standards to appeal to prospective buyers especially from North and South America and wherever launches of first-class construction are required. During visits to overseas ports *Tonquin* will serve to introduce the "Two-Way Tension" system of construction and its resultant advantages to users of marine transport in those countries.

The "Two-Way Tension" system, developed and patented by Mr. Brian Grimston, Chairman of the Company, has been used in the construction of 600 light alloy craft completed at Bideford in the past five years. Of these, over 500 craft, including survey and coastguard launches, are now in service abroad. These figures confirm the increasing popularity of marine light alloys of the type which for years have been accepted by Lloyds. This form of construction results in great strength, high speeds, reduced fuel consumption and low maintenance costs as such craft are impervious to the effects of teredo worm and other forms of marine life which attack ships made of orthodox materials. For overseas buyers an added advantage is that craft built by this method can be crated in "the flat state" and assembled abroad.

The Swinden Laboratories

With the expansion of the Central Research Department of the United Steel Companies, Ltd. into a Research and Development Department came a demand for increased accommodation. This has been provided by the new Swinden Laboratories at Rotherham, and in the following brief account reference is made to some of the activities of the various sections.

SOME idea of the importance attached by the United Steel Companies, Ltd. to its Research and Development Department—itself an indication of the service the Department has given to the Company—can be gained from the fact that, although it is less than twenty years since the "new" Central Research Department at Stocksbridge was opened by Lord Rutherford, it has been necessary to build a new block of laboratories, four times as big as the old one, and housing a staff which has grown to an even greater extent, and which includes not only physicists, chemists and metallurgists, but also geologists, mathematicians and a large group of development engineers.

The original research team, working under the Directorship of Dr. Thomas Swinden, rapidly established for itself a high reputation in the fields of chemistry, metallurgy and refractories. With the untimely death of Dr. Swinden in 1944, it was decided to expand the activities of the Department. The new Director of Research, Mr. Frank Saniter, was chosen because, in addition to his training as a mechanical engineer, he possessed a wide background of experience in the steel industry.

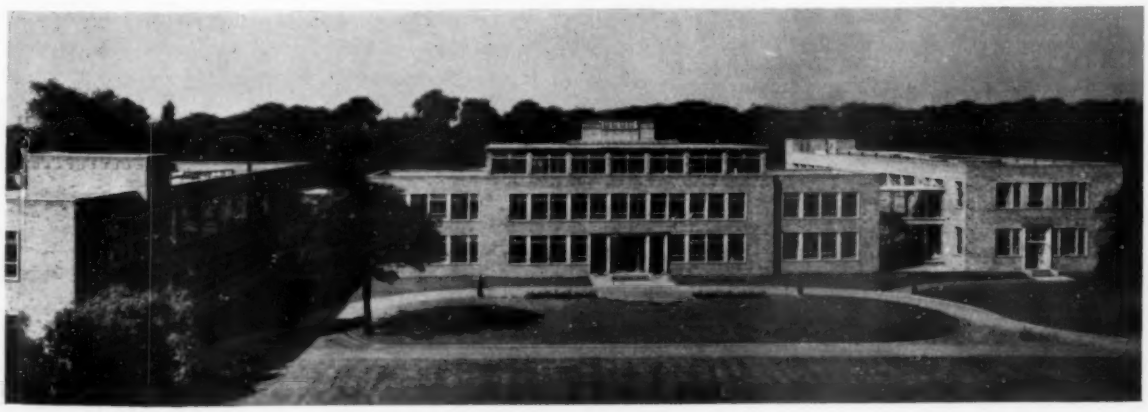
The first step in the expansion scheme was the formation of a group of development engineers to specialise in iron and steelworks plant. A Minerals Section was started to cover raw materials and ore dressing methods, and increased interest in open-hearth furnaces led to a demand for new laboratories where air, water and hot gas flow could be studied. It was this expansion of activities which forced the first transfers from Stocksbridge to the new site in Moorgate, Rotherham. The old "Red House" and now the completed laboratories were given the name of "Swinden" in honour of the first Director of Research.

The new laboratories serve the biggest group of iron, steel and coke producing units in the British Commonwealth, a group which is unique in this country in that, although other concerns deal with the whole series of operations from ore mining to finished steel, none has so varied a range of end products, including, as they do, highly alloyed steels in the stainless and heat-resisting classes. The constituent companies enjoy a good deal of autonomy, each being responsible for the production and sale of its own products, and maintaining its own research department (well equipped for chemical and metallurgical work) and its own staff of development engineers. The staffs of the branch laboratories are mainly concerned with production control at all stages, but their work carries through to the application stage and, indeed, includes the development of new materials for special purposes.

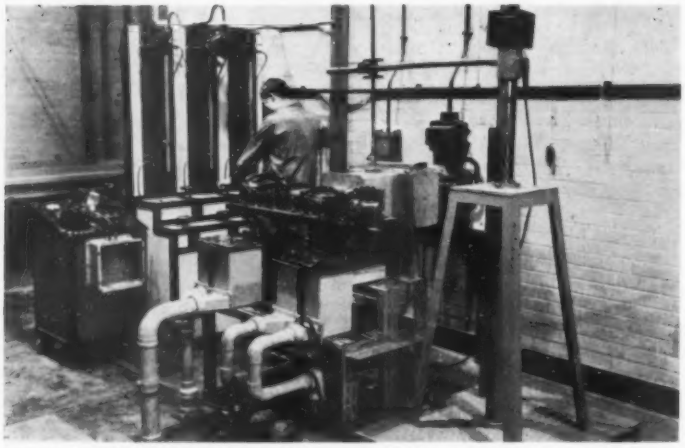
The Company is fortunate in possessing a good committee structure, which not only prevents overlapping between Swinden Laboratories and the branches, but also makes for excellent co-operation. Research on chemical and metallurgical matters is mainly co-ordinated by the Research Directing Committee and its sub-committees, whilst plant problems are discussed by a series of technical committees. Problems arising from customers' requirements are discussed at frequent meetings with the commercial managers. This set-up enables ideas conceived at all levels to be discussed, developed and, where practicable, applied with unusual speed. At a higher level, there are the Managing Directors' Advisory Committee and the Works Managers' Committee, on both of which the Department is represented by the Director of Research.

Methods

Roughly one-half of the research and development work originates in works requests for help in overcoming an operating difficulty, or for new procedures to increase production or effect economy. Following a research



General view of the laboratories.



View of water flow laboratories showing a model of an open-hearth furnace.

conference an attempt is made to state explicitly the nature of the problem and the recommended approach, together with a note of the sections co-operating and the branches likely to be interested. This enables the section man to plan his work and priorities to be given for the various investigations in hand. These are decided on the relative importance of the job and the probability of a solution being reached within a reasonable time. Flexibility of outlook is essential, since research means exploration of the unknown and, therefore, frequent changes of plan. Increasing importance is attached to a relatively new conception in industrial research, viz: the formation of a small highly trained team, seconded from a number of different sections, to tackle in close collaboration with production men some particularly urgent problem. For a limited period sectional interests are sacrificed to the demands of the particular situation, the major advantage of this approach being the close integration of research and application, any ideas that emerge being immediately tried out in practice.

Staff

The opinion has been expressed that these laboratories are, amongst those attached to steel companies, the finest in the world, but not all the best scientific work is carried out in ideal surroundings, and what really determines the efficiency of a department such as this is the quality of the personnel employed. Although technical competence must always be the primary qualification for a good research or development man, it has been assumed from the start that the ability to work in a team is almost equally important, particularly in these days of specialisation, where so often no one man possesses the knowledge or experience necessary to a complete solution of the problem.

Given the demand by the practical man for the solution of a problem the next stage is usually a discussion, either at the works or in the laboratory, at which those able to make a useful contribution are present. Once the nature of the problem has been agreed, a decision as to the most appropriate team and leader can be made. The Department is fortunate in possessing men with a wide diversity of skills; this enables a new idea, emerging perhaps from some apparently academic research, to be considered from many angles, and a quick decision reached as to whether it should be pursued and, if so, in what way. Nor is it sufficient to find good men: they must stay good. If they are to do so they must have ample opportunity for widening their experience by association with other equally keen and qualified people. It is for this reason that the staff of the Department are encouraged to be members of appropriate technical societies and arrangements made for many of them to travel widely both at home and abroad in pursuit of knowledge produced by other workers, which must inevitably be far greater in total than anything they produce themselves.

Turning from quality to quantity, we may note that, whereas the employees in 1934, when the Stocksbridge laboratories were opened, numbered only twenty-five, there are now one hundred and eighty on the research, development and administrative staff. Of this total, some forty are University graduates, and over eighty technically qualified in some branch of science or technology.

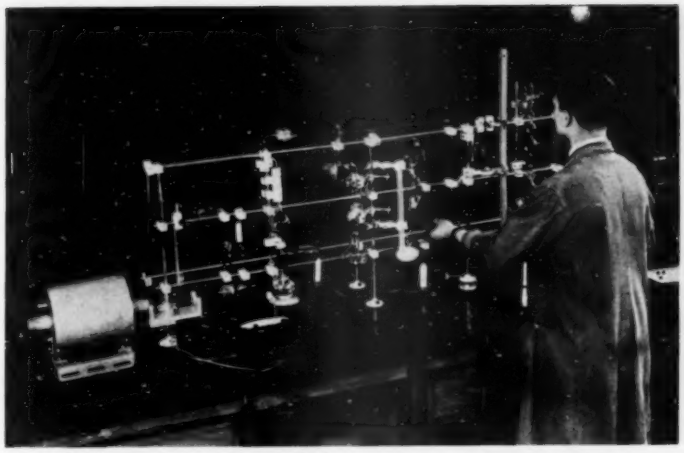
The scientific and technical work of the Department is the immediate concern of the Assistant Director of Research, the Research Manager and the Development Engineer, the various sections being for convenience divided into three groups responsible to these executives. The Secretary is responsible to the Director for administrative matters, and for the library and information service. He is also Secretary to the Research Directing Committee and its various sub-committees. Further reference to the individual sections will be made later.

Buildings

Apart from Swinden House, which is occupied by the Director of Research, the administrative staff and the library and information service, there are four main

A battery of creep-testing machines.

laboratory blocks. Block C, in the centre of the picture on page 89, besides housing the Assistant Director of Research, the Research Manager, and the Development Engineer, provides office accommodation for the development engineering staff, the top floor comprising a particularly well-lit drawing office. Blocks A and B, on the left and right of the illustration, respectively, and the ground floor of Block C, consist of laboratories varying greatly in size to meet the needs of the type of work involved. Block D, which is a high single-storey building on the portal frame principle, was designed for pilot plant work and is, therefore, equipped with overhead cranes and movable partitions: it is located behind Block C and is not visible in the illustration. The unique trio of air, water and hot gas flow laboratories are located in one end of this block. Although devoted primarily to research, they tie in both figuratively and literally with the development sections, pilot plants having already been built that bridge the parts originally specified for "research" and "development."



Equipment used for the determination of gases in steel.

Activities

Minerals.—The Company is fortunate in being able to obtain the bulk of its raw materials in Great Britain, and their location, distribution and properties are the subject of wide yet fundamental studies in the Minerals Section. From a study of existing information and the results of boring operations, plans are made of existing workings and recommendations given regarding future development. Considerable work has been carried out on the self-fluxing Frodingham ore/Northants ore burden used for the large iron production at Scunthorpe, as both these ores are low in iron (22–35%). Normal concentration methods show little signs of promise due to the finely disseminated character of the iron-containing minerals. The most encouraging procedure to date is the screening and sintering of the fines, which eliminates most of the sulphur and virtually the whole of the carbon-dioxide and water, besides improving furnace operation. A miniature sinter plant has been built at Swinden Laboratories to study the effect of variables on the process. Other raw materials studied include refractory materials, moulding sands and fluorspar.

Refractories.—With an annual expenditure of more than £1,000,000 a year on refractories, routine control of quality and research on possible economies are obviously essential. Work in this field can be divided under three main headings: the development of new products; special tests; and standard testing.

Since 1934 there has been close co-operation with the manufacturers of refractory materials, for the user, provided he also understands the brick-making side, can make a real contribution to the art. The development of the stabilised dolomite brick offers a good example of such collaboration, for it was the X-ray examination of samples obtained from unsuccessful trials that provided the fundamental answer to the problem. Another major co-operative project was the production of British carbon blocks for use in blast furnaces and their subsequent trials, not only in the hearth and bosh, but also in the stack: breakouts at Scunthorpe have been virtually eliminated by their use. The improved performance of silica bricks made from imported South African material has resulted in an intensive search for better silica rocks in Britain and elsewhere.

The development of special tests—such as shot blasting for the determination of abrasion resistance—has often led to the detection of unsuspected differences between bricks, and to information of fundamental importance being obtained by further investigation.

Fuels and Furnaces.—Interest in this field at Swinden Laboratories is confined to steelmaking and reheating as the laboratories at Orgreave deal with coke. Valuable background information on combustion and heat transfer was provided by the Templeborough trials on open-hearth furnaces which were completed in 1946, and by recent similar trials on a continuous billet reheating furnace. The Templeborough trials revealed almost complete ignorance of flow conditions within the furnace chamber and, as a result, an intensive investigation of flow problems was started, beginning with the construction of small scale water models, using suspended aluminium particles to show the flow. These investigations showed most unexpected results, but as a result of several years' work it is now possible to trace the flow pattern through simple two-dimensional and three-dimensional models to scale models of furnaces and, finally, to the actual furnace itself. The importance attached to flow patterns, in all types of furnaces, is shown by the inclusion of a group of three laboratories, where air flow, water flow and hot gas flow can be studied. Such research work, aimed at greater production and improved economy, must be backed up in the application stage by other engineering explorations. Thus, in open-hearth operations, charging means and methods are involved and the design of such ancillaries as flues and reversing valves. The application of all available knowledge to the design of such equipment as soaking pits, reheating and heat-treatment furnaces and boilers, has been made the special job of the Development Group, who have made a particular study of heat exchange problems.

Iron and Steelmaking Plant.—With the formation of the Development Group in 1945, the Department entered the field of plant developments. The work falls into two categories. The first involves new principles and the follow-up of new processes suggested by labora-

General view of the library.

tory work, sometimes through pilot plant stages of increasing size. The aim in the early stages is to gain data on the operation of individual units of plant, from which successively larger units can be designed, whilst in the later stages such units are integrated into a complete plant. The second category involves no new principle but calls for a study of the operating characteristics of existing full-scale plant, the results being applied to the design of future installations or the modification of those already in use.

Forming of Metals.—The wide variety of metal forming plant in operation at the branches ranges from heavy blooming mills and forging presses to precision cold-rolling mills for thin gauge strip, and fine wire (0·001 in.) draw benches. The theory of plastic deformation as applied to metal forming processes is by no means complete and practical tests are carried out on the plant to provide fundamental data on which future designs can be based. The Department is also available to advise on the technical and economic aspects of the modernisation of existing plant, to investigate new types of plant and new processes, and to study detailed items of production equipment with a view to improving output or quality.

Metallurgy.—In many of the fields served by the Company's products there is a continual demand for new and better materials, which in turn means research on the effect of composition, steelmaking, forging, rolling and heat treatment ; the much publicised failure of certain welded ships has shown that ordinary mild steel can still present a major problem. The scale of this work can be judged from the fact that over eight thousand experimental casts have been made in the laboratory high-frequency furnace since the Department first opened in 1934. The laboratories are equipped for carrying out controlled heat treatment, micro- and macro-examination, tensile and impact tests at normal and elevated temperatures, hardenability, torsion, fatigue, creep, wear and damping tests, etc.

Of the many contributions made by the Department to the development of new and improved steels, one is worthy of special mention, viz : the discovery that the addition of a minute amount of boron (about 0·002%) to a steel of specific composition and containing 0·10% carbon, resulted in a doubling of the yield strength. The combination of such high strength with good weldability has led to its application in a number of important fields and opened up lines of research that will continue to be explored for some time to come.

The spectacular developments in the gas turbine field have somewhat overshadowed the progress which has been made in steam turbine practice. In both cases improved results are due in no small measure to the production of materials having better creep properties. The length of time taken to carry out creep tests for steam turbine materials necessitates the tying-up of expensive equipment for long periods so that a large number of testing machines is required. Part of the battery at present employed may be seen in our illustration.

The progress of welding has been so rapid that to-day the introduction of any new metal to industry is greatly dependent on its suitability for welding. Although the diverse products enter most of the industries in which welding is applied, it was as manufacturers of welding wire that the Company made a specialised study of the subject. To-day the laboratories are equipped for metallic arc, atomic hydrogen, argon arc, oxy-acetylene and electric resistance welding. The main tasks are to assist customers with their welding problems, to recommend suitable welding methods and materials for particular applications, and to co-operate with the B.W.R.A. and the B.S.I. Welding Committees in their work.

Chemistry.—The analytical laboratories are equipped to carry out all types of analysis of iron and steel, and a good deal of work is done on the development and improvement of analytical methods. Special laboratories are equipped for the study of corrosion and corrosion prevention, a special feature being the apparatus for the continuous measurement of high-temperature corrosion or scaling in various atmospheres.

Experimental casts up to 18 lb. in weight are at present made in a high-frequency induction furnace, but it is intended to extend the melting facilities by the addition of a unit capable of melting larger quantities of steel, not only under normal conditions but under vacuum or controlled atmosphere. Chemistry also plays its part in improving the efficiency and increasing the economy of the iron and steel making processes, both by laboratory work designed to improve knowledge of the fundamental principles involved, and by investigations on the plant to help in the solution of more immediate problems.

It is now known that small quantities of oxygen, hydrogen and nitrogen dissolved in steel have a profound effect on the behaviour of the steel both during manufacture and in subsequent service. Much pioneer work has been and is still being done on the determination of these gases with a view to their control.

Physics.—What may be termed laboratory physics is concerned with the determination of physical properties of steels, refractories, quenching oils, etc., and with work on isothermal transformation in steel. Other activities under this heading include non-destructive testing, strain-gauge and photo-elastic work, and radioactive tracer techniques. Some of the physical investigations, on the other hand, must be carried out on the plant as,

for example, the use of strain gauges to determine the loads in rolling mill plant.

Although it is mainly in the field of refractories that X-ray work has given the most dramatic results, extremely valuable information has also been obtained on both slags and metals. Valuable work has been carried out on carbides, nitrides and inter-metallic compounds removed from alloy steels by electrolytic solution, and on surface films and scale layers. A second X-ray unit will be capable of operating at high temperatures under vacuum or controlled atmosphere.

Mathematics.—The Company was one of the first in the steel industry to show an interest in the application of statistics to works problems. The complexity of iron and steel works operations and the lack of quantitative knowledge of many factors governing output and quality make this a very rich field of study, and although the Statistical Section was only started in 1946, it has already tackled a number of most important problems.

Library and Information.—Both research and development are heavily dependent on facts discovered by others, and the Department relies for its knowledge of such facts on the information service with its up-to-date library of text books and technical journals. The kingpin of the service is the information officer, who, by keeping in touch with what is going on in the laboratories can frequently refer the staff to specialised articles which may have been written for some apparently unrelated purpose.

Correspondence

The Editor, METALLURGIA.

Sir,

The paper on "Some Experiments with Ductile Cast Iron," by Messrs. C. C. Hodgson and C. S. Johnson, in your May issue, is a valuable contribution to the subject and will be helpful to foundrymen and metallurgists engaged in the production of spheroidal graphite cast iron.

The authors mention some difficulties encountered in slag removal after inoculating with magnesium. As we are also engaged in the production of spheroidal graphite cast iron and encountered the same trouble some time ago, I should like to take this opportunity of stating some of our experiences in slag removal. At present we are successfully using for this purpose coal dust which is

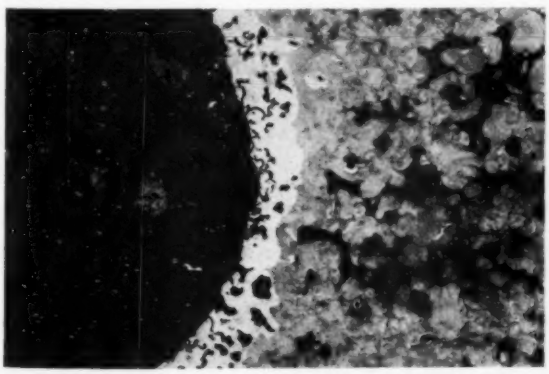


Fig. 1.—Spheroidal graphite cast iron showing graphite flakes in the vicinity of slag. 4% picral etch. × 100

sprinkled on the surface of the metal after inoculating it with magnesium. No exact quantity is specified, but a handful is sufficient for 1 cwt. of metal when used in this way in our foundry. The coal dust helps to collect the slag in a solid mass which is easily skimmed off, leaving a clean surface of metal. We have tried dry silica sand, but coal dust has proved more satisfactory for this purpose. The coal dust should be coarser than that used for the normal foundry operations. It is also our experience that a little turbulence will bring up more entrapped slag to the surface of the metal, from which it

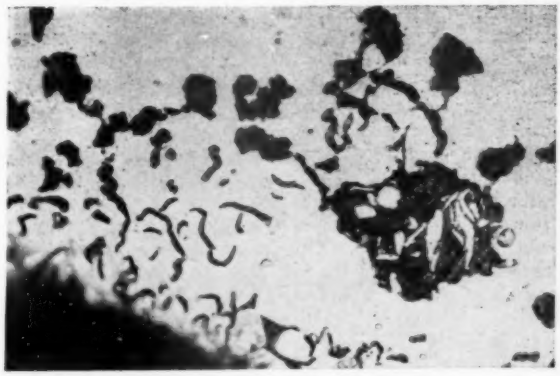


Fig. 2.—As Fig. 1, but at a higher magnification. Unetched. × 600

is easily removed by skimming off during the time of pouring. A skimmer which has been found satisfactory for the purpose can be made from ¼ in. thick steel plate, cut to the shape of a segment of a circle (less than a semi-circle) and riveted to a ⅜ in. diameter steel rod, inclined at an angle to the plane of the plate. The radius of the blade should be coated with a thin refractory wash and dried before use. It has been found that after using the skimmer for four or five ladles metal sticks to the blade. This can easily be removed when hot either by hammering or by striking it against an iron block. A new refractory coating is then applied before re-use.

In order to prevent slag entering the mould, the metal is poured at such a rate that the pouring basin is always full, and the slag is thus kept at the surface of the metal.

Not only does the entrapped slag promote unsound castings but it also produces a deleterious effect on the solidification of spheroidal graphite cast iron, in that it prevents the formation of nodules, as is clearly evidenced from Figs. 1 and 2 which show small flake graphite around slag in a pearlitic spheroidal graphite cast iron. Although a satisfactory explanation is not yet available, it is assumed that the slag destroys the nuclei for the nodules and thus promotes graphite flakes in its neighbourhood.

Yours faithfully,

G. SINGH,

Representative of Messrs. Greysham & Co., Engineers.

Delhi, 13.6.52.

The Plansee Seminar

A Brief Account of the Conference Proceedings

By a Special Contributor

THE Metallwerk Plansee, now in its thirtieth year, recently invited international experts to a four-day Conference, which was held at the works at Reutte, from June 22nd to June 26th, 1952. A total of some 300 scientists, from Austria, Germany, Britain, Switzerland, Sweden, the United States, France, Holland, Italy, Liechtenstein, Belgium, Finland, Luxemburg and South Africa, attended the Seminar and listened to 31 lecturers dealing with the following main themes: physical metallurgy; hard metals; and general powder metallurgy.

The purpose of the meeting, as outlined by the President, Dr. P. Schwarzkopf, was to bring together industry and science and to bridge the considerable differences in development in America and on the Continent of Europe. This latter statement was rather surprising in view of the fact that for a number of years now, European experts have been working in the United States and have acquired important positions in science and industry. This well organised meeting left the visitor with the feeling that a basic understanding of powder metallurgy has been reached, that powder metallurgy is no longer a specialised field to be left to the expert, and that, as in other branches of technology, there are now no particular secrets to be guarded. Those who have spent a lifetime working on powder metallurgy probably now realise more and more that the period of the " cookery book " technique must be ended and the engineer must acquire sufficient knowledge to enable him successfully to develop and apply powder metallurgy parts.

The languages used at the Seminar were German and English and, occasionally, French. Brief abstracts of all the papers were available in English and German, but they were not sufficiently detailed for the listener who was conversant with the technical field concerned, but who was not conversant with the language of the lecturer: this comment refers particularly to relatively new scientific investigations. Only those who had a knowledge of German and English could make full use of the information offered. On the other hand, the Seminar will have demonstrated some European ideas to Anglo-American scientists, and vice-versa. The themes discussed were not strictly confined to powder metallurgy, and such general topics as hardness and wear resistance were discussed, as well as general metallurgical problems on electron emission, diffusion in thin layers, etc.

The first lecture of the Symposium was presented by Prof. F. Skaupy, of the University of Berlin. Prof. Skaupy, now in his seventieth year, contributed considerably to the development of powder metallurgy and wrote the first text book on the subject, which he named Metallkeramik.[1] At one time there was considerable discussion as to whether the name was suitable, but now, through the cermets it has gained added justification. The Montanistische Technische Hochschule in Leoben recently conferred on Prof. Skaupy an honorary doctorate.

PHYSICAL METALLURGY

In his paper on present-day views on the nature of metals, and their significance for powder metallurgy, Prof. Skaupy emphasized as the main properties of metals their electrical and thermal conductivities, brilliance, etc., and pointed out the influence of interatomic distances on electrical conductivity. This problem has been investigated by H. Meyer, who determined the specific resistance of cesium in relation to film thickness. Electrical conductivity started when the thickness was about 23 atomic layers (one atomic layer of cesium = 6 AU). The same effect was obtained with 15 atomic layers of mercury and 5 atomic layers of thallium. Klemm has established a classification of real metals, meta-metals and semi-metals: in this classification, zinc appears as a meta-metal. Attention was drawn by the lecturer to the interesting investigations of J. Kramer[2] on the metallic phase. When the surface of a metal which has only just been machined or ground is tested, it is found to emit electrons, the number falling rapidly according to an exponential law. Electron emission can also be produced by heating the metal, and there are certain points at which the emission is suddenly increased. These values have been determined by several methods and the idea of a certain non-metallic phase conceived.

As indicated by the lecturer, and further emphasised during the discussion, the results indicated by Kramer call for a careful rechecking. In conclusion, Prof. Skaupy referred to the interesting work carried out by Kantorowicz in his laboratory about twenty years ago, on the conductivity of powders under pressure. Tungsten powders of 10 micron grain size were subjected to increasing pressure during successive pressing operations up to a total of 70. The initial high resistance fell to a low value after the first application of pressure, decreasing slightly as the pressure was increased to its maximum value. With successive compression cycles, the resistance fell in each case with increasing pressure, but at the same final pressure, the resistance increased with the number of compressions. Again, this phenomenon may be due to a non-metallic phase.

Prof. R. Walzel, of the Montanistische Hochschule, Leoben, discussed the principles of dry metallic wear, and referred to the new German draft standard DIN 50320, in which definitions of wear are given. Wear is therein stated to be a slowly progressing harmful separation of small particles through mechanical causes. This definition, therefore, excludes fracture, intentional removal of material as in grinding, plastic deformation

and corrosion, as well as by fretting corrosion which may be due to both chemical and mechanical action. Dry wear requires, in principle, a sliding movement, but when two rollers roll under pressure, one against the other, although no apparent slip occurs, a condition of true wear exists. One of the factors influencing wear is the local welding together of the two rubbing surfaces where there is high localised pressure. On subsequent separation pieces are torn out. Examples include the built-up edge and the erosion of the rake face on cutting tools, pitting in gears, and the sliding of railway wheel rims. Prof. Walzel then proceeded to a detailed analysis of wear and said that it is considered to be due to friction forces in excess of the tensile and shear strength of the surface layer. It is difficult to predict wear resistance from hardness tests and to draw conclusions from laboratory tests as to the performance to be expected in service. These difficulties are due to the complicated dependence of friction forces on many factors, as well as to the fact that the tensile and shear strength of the surface layer are not constant, but are determined by the changes taking place during wear. The special conditions determining the wear of sintered materials were pointed out and attention drawn to the striking similarity between cast iron and powder metallurgy parts in their wear behaviour.

Next, Prof. A. G. Smekal,[3] of the University, Graz, dealt as one with authority on the subject of ideal and real crystals, a field in which he has worked for some considerable time. He distinguished between the structure-insensitive and structure-sensitive properties. The former are independent of the pre-treatment or history of a material, whilst the structure-sensitive properties, on the other hand, depend on the previous history in a chemical and mechanical sense, and are not properties of the lattice. Even the single crystal has a microstructure in that there are defects in the lattice, impurities, etc., which have considerable bearing on the properties, and Prof. Smekal discussed these points together with the effect of lattice structures and chemical bonding types (*e.g.* on self-diffusion and plastic deformation), and the characteristics of ideal structure elements

Hardness

Prof. R. Mitsche, of the Montanistische Hochschule, Leoben, reported some work which led to the suggestion of a uniform hardness test. Technical hardness test methods are generally based on the determination of the "indentation hardness." In these methods, three types of penetrator are employed : balls (Brinell), cones (Ludwik and Rockwell), or pyramids (Vickers), and, in consequence, a series of different hardness scales is in use. As a result of an extensive series of tests, covering the range from soft aluminium to fully hardened steels, it has been shown that a 136° pyramid of sintered hard metal permits the development of a uniform indentation test (pre-loading procedure). The evaluation can be based either on the depth of penetration or on the computation of the Vicker's hardness number in kg./mm.^{2} Although a number of considerations favour the use of a set of different loads, Prof. Mitsche suggested the use of one load only, preferably 150 (140 + 10) kg. The use of a 120° cone instead of the 136° pyramid is possible but, in general, less advantageous.

New concepts of the diffusion of metals were discussed by Prof. W. Seith, University of Münster. If two metals are in contact, under favourable conditions, diffusion of one into the other may take place, and the problems involved are now being studied with the aid of radio-isotopes. In all types of diffusion a change of position of atoms is assumed. One of the consequences of the action, on the presumption that the lattice structure remains undisturbed, is the appearance of pores and holes. When two solids are in contact at elevated temperatures and diffusion takes place, a bulge is formed, followed later by a contraction, and at certain distances from, and parallel to, the contact face a series of holes or pores appear. To one metal more material is added, and from the other material is taken away, and there is a stage of removal leading to the formation of a series of holes which can apparently move through the material.

In the discussion, H. Bückle stated that he also had observed similar holes and hole series, and had determined their migration by placing micro-indentation marks at certain distances and observing how these distances changed after diffusion. The walls of the holes seemed to have a definite orientation as shown by some photomicrographs. To a question by Prof. Nowotny as to why these phenomena had only been observed recently, Prof. Seith replied that they had been known for a long time, for instance in welding, but had usually been attributed to the carelessness of the operator. Baines has shown these holes by X-ray diffraction.

Prof. H. Nowotny, University of Vienna, dealt with the bonding in intermetallic phases, and restricted his considerations in the main to monocarbides. Based on a discussion of a series of isomorphous compounds, he attempted to distinguish between the different types of bonding. In particular, he dealt with the extent to which simple relationships can be expected between the type of bonding and specific properties such as hardness.

A most interesting paper on the electron theory of mechanical strength or hardness was presented by Prof. G. M. Schwab, University of Munich. An approximate theoretical treatment of the temperature coefficient of the penetration hardness of metals permits the derivation of the energy factors determining plastic deformation. While previously the strength could be related to atomic dimensions only, the new theory leads to a relationship between the formation of dislocations and the electron structure of metals. The macro-hardness, as in use to-day, is not well defined as it is obviously affected by temperature as well as by cold working and plastic after flow. Considering a solid body as a free but degenerated electron gas, the hardness increases as the number of the free electrons decreases. The energy characteristic has to take into account the temperature coefficient. An attempt has been made to utilise the critical shear stress and the deformation speed as given by Smekal, Beck, Orowan and Kochendoerfer, but no good relationship with hardness can be established. Later considerations led to a semi-empirical formula :

$$H = \frac{v_K \times 10^3/T}{Ae^{\frac{-E_1}{RT}} + Be^{\frac{-E_2}{RT}}}$$

the denominator expression of which is similar to the semi-conductor formula. This theory expresses the hardness in relation to the inverse of the temperature ($10^3/T$) and is expressed graphically by two straight lines joined by a transition curve. The semi-empirial

solution has been tested experimentally in a simple hot hardness tester, in which an eccentrically arranged steel ball can be rotated over the test piece in an electrically-heated furnace.

Dr. Auwärter, of Messrs. Balzers, Liechtenstein, in his paper on the stability of inorganic compounds in high vacuum, discussed the processes taking place during the melting of inorganic compounds, particularly of oxides, in high vacuum. The dissociation pressure of oxygen, as well as possible reactions with the environment, play a decisive part.

The effect of adsorbed gases on the reactivity of solid surfaces was dealt with by Dr. H. Forestier, the University, Strasbourg. The effect of gas adsorption on the stability of crystal lattices was investigated. This effect is evidenced by : (1) change of reactivity of solid oxides ; (2) change of transformation temperature of polymorphous substances in powder form ; (3) change of melting point of crystalline substances. The experimental data permit a theoretical interpretation of this phenomena. The gas, which is adsorbed by Van der Waals forces, effects changes in the stability of the energy levels of the solid surface.

A novel heating apparatus which can be mounted on a microscope stage was demonstrated by Dr. A. Kofler, of Innsbruck. With this he can apply two micro-thermal analysis methods : (1) a contact method, and (2) fusion and crystallisation of solid solutions. Both methods were demonstrated in microfilms. The film on the contact method showed the behaviour of a binary system on formation of (*a*) a simple eutectic, (*b*) one or more molecular compounds, (*c*) miscibility gaps of liquid phases, and (*d*) solid solutions. The second microfilm showed the homogenisation of solid solutions upon heating and cooling within the interval between solidus and liquidus. It was demonstrated that this homogenisation is not a pure diffusion process since periodical transformations play a contributing part. A homogenisation of zone crystals within a few hours is possible only in the presence of small amounts of melt.

HARD METALS

Prof. J. T. Norton, M.I.T., Cambridge, Mass. discussed the ternary system tungsten-carbon-cobalt. Although alloys of tungsten monocarbide and cobalt have been extensively studied and widely used in practice, there is still considerable uncertainty about the nature of the true ternary phase diagram. Experimental investigations have established the ternary isothermal section at 1,400° C. and have shown in addition to the well-known eta phase, two new ternary phases corresponding approximately to the formulae $Co_3W_6C_2$ and $Co_3W_{10}C_4$; the former has a cubic lattice and the latter a hexagonal one. Isomorphous phases were observed in the analogous systems containing iron or nickel. The reactions leading to the formation of these phases have been determined and a tentative phase diagram proposed. Evidence for the existence of stable and unstable equilibria was presented, and on the basis of the proposed diagram, the reactions during the sintering of alloys of tungsten carbide and cobalt were examined and some of the details of the structure and properties of sintered carbide compositions discussed.

A joint paper by Dr. T. Raine and Dr. R. Edwards, of Manchester, was read by Dr. Edwards and dealt with the solid solubilities at 1,250° C. of various carbides in the bonding metals, cobalt, nickel and iron. No evidence of the solubility of cobalt in tungsten carbide was found. The solubility was determined both metallographically and by X-ray methods. The behaviour of nickel alloys differed considerably from that of the cobalt alloys. In the discussion, Dr. Krainer referred to his investigations of the eta phase, and pointed out that a wide range of stability makes its placing in the phase diagram difficult. Further investigations are necessary to evaluate the boundaries of the various phases. Kiessling referred to variations in the parameters of the eta phase.

In dealing with the problem of preparing pure titanium carbide, Prof. G. F. Hüttig, Technical University, Graz, said that in such a case the following requirements should be fulfilled. First, the chemical composition should correspond to the chemical formula, secondly, the free carbon content should be as low as possible, and thirdly, the particle size distribution should be within certain limits. The principles of inorganic chemistry, mainly based on the activated state concept, were reviewed. According to the gas atmosphere in which the carbide formation takes place, this atmosphere may have (1) a purely catalytic effect, (2) may act as pace-maker for the main reaction, or (3) may participate in the reaction. In case (3) one must distinguish between a direct carburisation by the gaseous agent and an indirect effect which can be described as the creation of equilibrium conditions prohibitive to the existence of free graphite. Other principles are based on the use of chemically active and therefore reactive starting materials which during the course of reaction produce, in statu nascendi, the components required for the carbide formation.

Solid Solution Formation

A survey of the formation of solid solutions of hard metals was presented by Dr. R. Kieffer, managing director of Metallwerk Plansee. The name hard metals refers to carbides, nitrides, borides and silicides of the transition metals of the fourth to sixth groups of the periodic system. The main constituents of modern tool materials are carbides of the transition materials and, particularly, binary and ternary solid solutions of these carbides. The solid solubility of the isomorphous carbides of the metals of the fourth and fifth groups as well as the partial solubility between these carbides and those of the sixth group metals was discussed. The cubic nitrides of the transition metals of the fourth and fifth groups form, with few exceptions, solid solutions with each other and with the isomophous carbides of the same groups. Borides and silicides of the transition metals have recently found application in high-temperature materials. While the carbides and nitrides have in general simple structures, the borides and silicides form a large number of hard metal phases with comparatively complicated structures. Isomorphous borides as well as silicides tend towards formation of solid solutions. The diffusion processes involved in the formation of solid solutions were followed by metallographic examination, and by microhardness measurements. The lecture was illustrated by a large number of well-made lantern slides, including some excellent photomicrographs.

Dr. E. Fitzer, Technical University, Vienna, reported on his tests with high-temperature materials produced by silicizing tungsten and molybdenum. Both tungsten and molybdenum, possessing a high-temperature strength, can be protected against oxidation by alloying

with silicon ; tungsten can be protected up to 2,000° C. and molybdenum up to 1,800° C. The silicides of these metals have practical importance either in the form of thin surface coating layers or as bulk materials produced by powder metallurgy. Surface layers can be produced by catalytic reduction of silicon tetrachloride with hydrogen, and this heterogeneous reaction can also be utilised for manufacturing $MoSi_2$ powders. The alloying of the pure components molybdenum and silicon in the solid state is too slow for the technical production of surface layers, but can be utilised for preparing sintered alloys. It was shown that should the thin surface layer crack, it could renew itself by growth of the layer. A film of 1 micron after ½ min. increased to a thickness of 5 micron in 5 min. The surface layers can be renewed frequently. A demonstration was arranged to show the application of these molybdenum materials as heating elements, whereby the molybdenum can replace pure platinum. In the discussion, Prof. Mitsche referred to this as a revolution in the design of melting furnaces and inquired about the properties of these conductors. Other possible applications are in gas turbines and rockets. Dr. Jenkins, G.E.C. Research Laboratories, Wembley, said that in his investigations on these heating elements, they did not prove useful for longer heating times than 200 hours. In his reply, Dr. Fitzer said that he tested these elements for short periods only.

Ing. C. Ballhausen,[5] of Krefeld, has developed diagrams to demonstrate the properties of hard metal alloys from their composition. The properties are plotted as space co-ordinates on a rectangular base having the volume ratio WC : TiC as abscissa and the cobalt content in area-per cent. as ordinate. Data on compressive strength, modulus of elasticity, hardness, modulus of rupture, coefficient of thermal expansion and cutting characteristics are plotted for WC-TiC-Co-base hard metals : each of these properties is represented by a surface. Standardisation of designations of sintered carbides, if possible on the WC-TiC ratios and cobalt contents was suggested.

In reporting on experiences with ceramic coated metals (vitreous enamels), metal-coated ceramics (mirrors, glass-to-metal seals), and metal-reinforced ceramics (Metalkase brick, wire glass), Prof. V. D. Frechette, Alfred University, N.Y., threw light on the newer field of metal-ceramic mixtures and suggested considerations to be applied in designing cermet bodies and coatings for high-temperature applications. Conversely, recent developments in cermets are suggestive of fresh attacks to old problems in the ceramic field.

Dr. R. Kiessling, Söderfors, Sweden, presented a summary of the work at Uppsala on ternary systems containing two transition metals and boron (Me_1-Me_2-B), also discussing the relative strength of the bond transition metal-boron. For the systems Mn-Fe-B, Mn-Co-B, Mn-Ni-B and Fe-Co-B, the range between 33 and 50 atomic per cent. boron has been studied. An equilibrium between two phases $(Me_1Me_2)_2B$ and $(Me_1Me_2)B$ exists and the directions of the tie-lines show that the metal with the lowest atomic number is always concentrated in the phase richest in boron. Distribution ratios for the metals Mn, Fe, Co and Ni between the boron-rich $(Me_1Me_2)B$ and the boron-poor $(Me_1Me_2)_2B$ phase have been calculated and a graphic representation of the equilibrium data was presented. These data show, that the strength of the metal-boron bond within a certain transition series decreases with increasing atomic number of the metal. The structures of ternary alloys of the type $(Me_1Me_2)B_2$ are also being studied and some preliminary results from these investigations were reported.

Dr. E. M. Onitsch-Modl, of Montanistische Hochschule, Leoben, showed how correctly applied micro-hardness tests could serve as a simple method of examining processes involving hardness changes. This method was discussed in relation to the alloying processes occurring during the sintering of iron-carbon alloys containing the carbide-forming elements—chromium, tungsten, molybdenum and vanadium. Diffusion processes, which take place during sintering, both in the basic material and on carbide formation, can easily be followed by micro-hardness testing. In the course of such work, it was found that the micro-hardness test could be applied advantageously as such, and as a supplement to metallographic methods in the examination of very fine structures. In the ensuing discussion, H. Bückle mentioned that he had determined by micro-hardness measurements the phases in W-Cr-Mo alloys, and P. Grodzinski referred to some new developments [6, 7] in micro-hardness testing using a double cone indenter.

GENERAL POWDER METALLURGY *

Some experiments on liquid phase sintering were reported by Dr. H. S. Cannon and Prof. F. V. Lenel, Rensselaer Polytechnic Institute, N.Y., who put forward some hypotheses relating to the mechanism of liquid phase sintering for discussion. The rate of densification and the microstructure of sintered compacts of the following powder mixtures were determined : iron-copper, copper-bismuth, copper-lead and tungsten-copper. The system tungsten-copper differs from the others investigated in that the solid phase has only negligible solubility in the liquid phase during sintering. Nevertheless, considerable densification was observed, the extent of which depended upon the sintering conditions. Predictions based on considerations of surface and interfacial tensions were made on how complete densification might be expected in such a system. The mechanisms of densification in the two types of systems were compared—those with and those without appreciable solubility of the solid phase in the liquid phase.

In the systems iron-copper, copper-bismuth and copper-lead, it was observed that under certain conditions the densification of the compacts was incomplete even though they were sintered for long times. The cessation of densification is attributed to the formation of a rigid skeleton of the solid phase during sintering. It is postulated that rigid skeletons can be formed when the ratio of the solid-solid to the solid-liquid interfacial tensions is favourable. Experiments were described supporting this rigid skeleton theory. The difference between the rigid skeletons in the systems studied in this investigation and those observed in certain cemented carbide compositions was also discussed.

Prof. G. J. Comstock and Dr. F. H. Clark, U.S.A., discussed the development of high strength heat treatable products from alloy powders. Continued progress in the United States toward the development, production and application of fully alloyed metal powders is one of the most significant factors in widening the field of powder metallurgy, and the authors described the types of materials now being produced, their general charac-

* The scheduled lectures by Prof. F. Sauerwald, Halle, on "Surface Layers" and that of Dr. W. J. Kroll on "Production of Metal Powders by Fusion Electrolysis" did not take place.

teristics, the present preferred methods of fabricating pre-alloyed powders, and the potentialities presented by the development of high-strength, high-density, heat-treatable materials. Progress in the general production of metal powder parts, and charts indicating the growth of the industry were also shown, together with examples of new products.

A simple instrument for determining the adhesive force of metal powders was described by Prof. E Cremer, Innsbruck University. The apparatus consists of a small table rotated about a horizontal axis. Some powder is dusted on this table, which is slowly rotated until the glide angle is reached and the powder drops from the table. When plotting the *mg.* sin α component against the *mg.* cos α component, a straight line is obtained which intersects the ordinate not at zero, but at a value H, H being defined as the adhesive force. Further investigations showed that the adhesive force is also dependent on the contact area F, and the average diameter of the particles d, thus leading to a specific adhesive force

$$h = \frac{H.d}{F}$$

As a result of a number of experiments, it was suggested that this apparatus might be useful for determining the average grain diameter with an accuracy of about 20%.

Lattice Changes and Sintering

Dr. H. H. Hausner, New York, discussed the effect of lattice changes on the sintering process.[6] Since the rate of sintering depends among other things on the mobility of the atoms within the lattice, reactions which create lattice imperfections, lattice disturbances or complete lattice changes may further affect the rate of sintering. The following reactions were discussed, and their effect on the sintering process analysed :

(1) *Reductions.* Example : $MO + H_2 \rightarrow M + H_2O$
(2) *Decompositions.* Example : $MH \rightarrow M + H_2$
(3) *Phase Changes.* Example : $M\alpha \rightarrow M\beta$

Experimental work described included :[7] (*a*) the effect of heating on nickel powder compacts in a stream of hydrogen at temperatures up to 100° C. and the changes in electrical resistivity ; (*b*) the heating of zirconium hydride powder compacts in vacuum, the decomposition of the hydride into zirxconium and its effect on densification and grain size ; and (*c*) the thermocycling of an iron powder compact around the phase transformation temperature and its influence on density, shrinkage and grain size. The experimental results showed that the three types of lattice change described above affect the sintering procedure considerably, although the changes do not always occur in a similar way.

Prof. Dr. G. Jantsch and Dr. F. Zemek, Technical University, Graz, reported on their observations on the deposition of chemically pure vanadium from the gas phase. The observation of black metallic mirrors in experiments on the disproportionation of tri- and dihalogenides of vanadium initiated attempts to produce pure vanadium powder. Vanadium tetrachloride, prepared by chlorination of ferrovanadium, was fractionated and distilled. Mixtures of the purified tetrachloride with purest hydrogen were introduced into a furnace preheated to 700° C. Purest hydrogen, introduced from the opposite direction, accelerates reduction by eddy formation. Chemical and spectrochemical analysis indicated that the vanadium powder thus prepared contains 99% V, remainder hydrogen. Debye-Scherrer diagrams showed a cubic body-centred lattice, $a = 3{\cdot}0204$ AU. Measurements in the electron microscope (15,000 ×) give the particle diameter as 0·2–0·3 micron, and electron-diffraction results agreed with the X-ray data.

Dr. G. Ritzau, Krefeld, Germany, presented a contribution to the physical analysis of the sintering process. The electrical conductivity and the thermoelectric potential appear particularly suited for a " physical analysis " of this type. Whereas the variation of the electrical conductivity is determined by both the change in porosity and changes of the microstructure which may be effected by diffusion processes, the variation of the thermoelectric potential is independent of porosity. The principles of the method were discussed for binary systems which exhibit either complete mutual solubility (copper-nickel) or complete mutual insolubility (copper-iron) in the solid as well as in the liquid states. The poor sintering performance of nickel is, among others, clearly indicated by this analysis. For sintered hard metals and sintered magnets, it was shown that the method is capable of recording the course of sintering in complex alloys.

Sintered Aluminium

The application of powder metallurgy to aluminium[9] was dealt with by Prof. A. von Zeerleder, Neuhausen, Switzerland. He first described the production of powders used for the manufacture of sintered aluminium (trade name SAP = Sintered Aluminium Powder). Very fine particles of an apparent density between 0·8 and 1 are produced which are of a flake-like form, passing a sieve of about 200–300 mesh, but having a thickness less than 1 micron. These flakes are covered by a thin oxide film. The powder is first cold pre-pressed at a pressure between 14 and 35 tons/sq. in. After being sintered at 500–600° C., the compact is hot pressed at 35 tons/sq. in. Cylinders prepared in this way are extruded at 500°–600° C. at a pressure of 35–70 tons/sq. in., the extruded material being then suitable for either die-forging or hot-swaging. Instead of being extruded, the cylinders may also be directly die-forged. The outstanding properties include the high normal strength and, in particular, the hot strength. The strength is dependent on the grain size and reaches, for powders of a particle size smaller than 1 micron, values exceeding 50,000 lb./sq. in. The creep strength of SAP at 400° C. is far superior to that of all aluminium alloys. Due to the very fine grain structure the material also exhibits a superior fatigue strength at high temperatures. Proved applications include its use for pistons. One disadvantage at present, as mentioned in the discussion, is the relatively high price owing to the lengthy processing involved.

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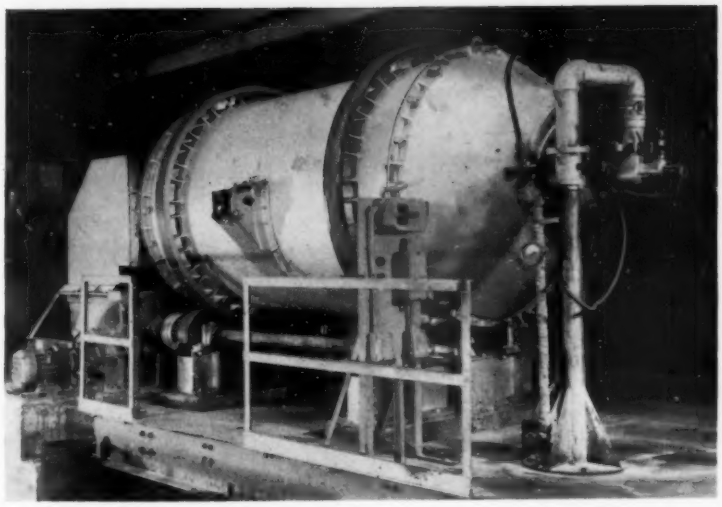
Rotary Melting Furnaces

Some Results Obtained with an Interesting Type of Equipment



Courtesy of The Monometer Manufacturing Co. Ltd.

Monometer fully-mechanised rotary melting furnace.

THE rotary furnace is a type which offers many advantages, especially for large-scale melting, both in the way of low consumption figures and labour costs. It consists in essentials of a horizontal cylindrical shell lined with refractory, with a pouring spout on one side and a slagging spout on the other. Originally, when these furnaces were employed for comparatively small melts of a hundredweight or so, this body was simply a drum-shaped shell mounted horizontally on trunnions, but a modern installation such as the one illustrated differs considerably from these somewhat crude beginnings. In modern practice, the ends of the body are of conical form, and spring-loaded to allow for expansion of the lining. The shell is now fitted with two machined tyres which are carried on two pairs of rollers driven through suitable reduction gearing from an electric motor. Rotation of the furnace is automatic, and operation is under push-button control, which makes it readily possible, when the melts are suitably staggered, for one operator to take charge of several furnaces. The burner fires direct into the furnace through one of the conical ends, the products of combustion being evacuated at the other end which also serves as a charging hole, for which purpose the modern design incorporates a retractable end flue which can be wheeled into position as soon as the charging of the furnace is completed, and serves either to evacuate the products of combustion to a stack or to a suitable metallic pre-heater in which the air supply for the burner can be preheated to 200–500° C.

Burners and Fuels

Such a furnace lends itself equally readily to firing by burners operating upon oil, gas, or pulverised coal, a single burner being used even for the largest sizes. For oil, the most suitable type is one with gravity feed, having primary and secondary air control, and requiring air at a pressure up to about 1 lb./sq. in. For gas, on the other hand, the best results are obtained with an air pressure of 3 to 4 lb./sq. in. A suitable tubular recuperator is invariably incorporated in the lay-out when the furnace is required for dealing with steel, cast-iron, and metals falling within the upper temperature range.

The wide field of foundry work for which the rotary furnace is suitable includes steel at the one end of the scale and aluminium and tin alloys at the other, oil being the fuel generally used for the higher melting temperatures, while oil and gas are capable of giving equally satisfactory results for the medium and lower range, the choice being largely governed by local considerations of prices and supplies. In a somewhat different field, the same type of furnace is used for melting enamel.

Typical Results

During a melt, the furnace rotates continuously at a slow speed, so that melting to a large extent is effected by radiant heat from the lining, and this principle has always been noteworthy for economy. For instance, even as far back as the period of the first world war, this type (which was then frequently known as a rolling furnace) used in a large Coventry foundry upon aluminium would give a consumption figure of 1·45 cu. ft. of town gas of 480 B.Th.U. per pound of aluminium melted, in the case of individual melts, while the average gas consumption at that time over an entire month's operation, including all starting-up and stand-by losses was only 3·4 cu. ft. per lb. To-day, modern designs of this type are being increasingly used for supplying the bale-out furnaces used in aluminium foundries.

It is useful in this connection to summarise some of the results which have been obtained in recent years with rotary furnaces both in English and continental practice, which will serve to show to what extent the type is capable of coping with increased production in the foundry and also of promoting increased efficiency in the use of fuel which has been the object of the campaigns conducted by the Ministry of Fuel and Power. The following figures are based upon the use of a furnace having 2 tons (brass) capacity with oil firing; melting times being those after the first heat, or with a highly preheated furnace.

Metal	Pouring Temperature ° C.	Consumption		Time per Melt min.
		Per long ton gal.	Per cwt. gal.	
Steel	1550	30	1·5	120
High-duty iron	1410/1450	25	1·25	90
Malleable	1400	30	1·5	120
Copper	1250	18	0·9	120
Gunmetal	1140	15	0·75	90
Aluminium	650/720	8	0·4	35

In the iron foundry, this type has been found very useful in the duplexing process in conjunction with the normal foundry cupola or for the intermittent feeding of ladles with molten metal. Quoting a continental result in this field, a 36-cwt. furnace charged with metal at 1,380 ° C. will raise this to 1,500 ° C. in 30 minutes with an oil consumption of 11·2 gal. per ton.

Turning to the non-ferrous side, used in melting and refining tin foil and ashes, a 3-ton furnace produces 1 ton of tin per hour with an oil consumption of 8 gal. per hour. A typical continental result with a smaller furnace of the same type charged with 693 lb. of hard lead ashes gave 486 lb. of ingot, melting time being 4 hours and oil consumption at the rate of 56 gal. per ton.

Reference has already been made to the employment of the rotary furnace for melting enamels, for which duty the usual calculation is 31 to 40 gal. per ton with a melting time of 55 to 85 minutes, the results varying greatly with the class of material, these figures being frequently exceeded in the case of difficult frits.

The lining of a rotary furnace may be either rammed refractory material, in the case of furnaces used for copper and for higher temperatures, or with high-grade firebrick in the case of lower temperatures. The useful life may be from 120 to 180 melts with malleable iron, 350 to 400 with copper and gunmetal, while with aluminium, on the other hand, the life of a brick lining may be anything up to 2 years.

Light Alloy Roofing at Alexandra Palace

DURING the war Alexandra Palace sustained extensive damage to the roof glazing, by both bomb blast and shell splinters, and by the beginning of 1950, this damage had been considerably extended by the weather. The wrought iron glazing bars and purlins, while badly rusted, were still considered of adequate strength; the bolts, however, securing glazing bars to purlins, and purlins to main arch trusses, were suspected to be dangerously weakened.

While this damage affects the entire roof of Alexandra Palace, the East Hall is the only part which has so far been re-roofed. A licence has been requested for similar work to be carried out on the West Hall, but it is unlikely that permission will be granted for the Centre Hall to be covered until 1953 or 1954.

After discussing various possible solutions, the Trustees eventually decided that the existing glazing bars and about 80% of the purlins should be scrapped, and that the Aygee patent system of curtain walling should be used to provide a roof of aluminium sheet and glass, of the same general outline as the old roof. It was considered that 16 s.w.g. Mansard pattern Rigidal corrugated aluminium sheet would be suitable, and that curving would be unnecessary provided lengths were kept short enough not to disrupt the impression of curvature.

The Aygee system is particularly well suited to work of this kind owing to its adaptability, coupled with low cost and speedy erection. This system is based on Aygee's patent BA glazing bar, which, by suitable modification of the extruded aluminium wing sections, can accommodate various infillings such as wired or clear glass, flat or corrugated aluminium or other metal sheeting, or standard insulation board.

The infillings on the Alexandra Palace roofs are Mansard pattern corrugated aluminium sheet and ¼-in. wired cast glass. On the roofs of the transepts and the East Entrance Hall, there are two runs of aluminium at the bottom, and two more at the shoulders, with the short vertical sides of the jack roofs also in aluminium. The remainder, including the pitched roof of the jack roof and three adjacent runs on the haunches, is glazed.

General view of the roof of the East Hall after covering with aluminium sheet and glass.

Of this total roof area about two-thirds is aluminium, one-third glazed. The dome is treated slightly differently, the only glazing being the pitched roof of the jack roof, and one run round immediately below the sides of this roof; the whole of the remainder is aluminium.

In all, this East Hall of the Palace has used some 12·8 tons of corrugated aluminium sheeting, 4·25 tons of aluminium glazing bars, about 1 ton of flashings, mainly in Super Purity (99·99%) aluminium, and about half-a-ton of fittings in the form of diecastings. The corrugated sheet was BA 60 (NS3) and the glazing bars BA 24-WP (HE9-WP). The whole of the light alloy material required for the work was supplied by The British Aluminium Co., Ltd.

NEWS AND ANNOUNCEMENTS

Conference on Scarce Metals

THE Leeds Metallurgical Society announces that the Conference on "Problems Arising from Metal Scarcities and the Use of Alternative Materials" which has been arranged for September 5th to 7th, will be held at the Becketts Park Training College, Headingley, Leeds, 6. This delightful spot is within three miles of the City Centre and is easily reached by tram or bus.

The introductory lecture to the Conference will be given by Mr. D. A. Oliver, Metal Economy Adviser to the Ministry of Supply, and Director of Research to the B.S.A. Group of Companies. A session on "Protective Coatings and the Use of Alternative Materials" will be opened by Mr. A. W. Wallbank, Managing Director of Messrs. Ionic Plating Co., Ltd. and Chairman of the Committee for the Development of Alternative Finishes. "Problems in Heat Treatment of Substitute En Steels" will be introduced by Mr. R. Wilcock, Chief Metallurgist, Samuel Fox & Co., Ltd., and "Substitution of Plastics for Metals," by Mr. J. M. J. Estevez of the Development Department, I.C.I. Plastics Division, whilst speakers of a similar standing will introduce other sessions on "Scrap Reclamation and its Contribution to Metal Supplies," etc.

Advanced Welding Course at Kingston Technical College

To meet the expanding needs of industry and to widen the basis of the existing courses, an advanced Welding Course is to be held at Kingston Technical College in the autumn term of this year. The duration will be for 15 weeks and the course will be held on Mondays from 7 p.m. to 9 p.m., commencing on Monday, September 29th.

The course is intended for those engaged in industry who require training in advanced welding processes to extend their knowledge to enable them to introduce new methods into manufacturing processes. The emphasis will largely be on resistance welding and the gas-arc systems in common use. This advanced course will include the relevant theory of the processes concerned together with machine manipulation and adjustment and will cover the application to ferrous and non-ferrous materials.

The Welding Laboratory is fully equipped for all normal requirements for training in gas and arc welding and has for a number of years provided theoretical and practical training for day and evening students, many of whom have been successful in passing the City and Guilds examinations. Further details of all Welding Courses may be obtained from the Head of the Engineering Department, Kingston Technical College, Fassett Road, Kingston-upon-Thames, to whom application for enrolment should be made.

Management Conference on Welding and Welding Research

THE British Welding Research Association recently held an interesting conference at Ashorne Hill. It was a Management Conference on Welding and Welding Research, and was the first of its kind ever held in this country.

The object of the conference was primarily to bring together for a short period in congenial surroundings leading men in industry who were either using welding with great success, using it a little, or not using it at all, with the idea that those in the last two categories could learn and be influenced by the favourable achievements of those of the first. To this end, experts lectured on the achievements of welding in the aircraft, structural, shipbuilding and chemical vessel industries.

The conference started with a session on research in industry at which the speakers were the Rt. Hon. the Earl of Halsbury on "The Government Aspects of Co-operative Research," Sir Wallace Akers on "What the I.C.I. owes to Research," and Professor J. F. Baker and G. Wesley Austin on the engineering and metallurgical aspects respectively of research at the B.W.R.A.

At the conclusion of the conference a glance into the future of welding was provided by Dr. A. B. McIntosh who spoke on "Welding Problems Encountered in the Production of Atomic Energy" and Major P. L. Teed who spoke on "Some Metallurgical Problems Imposed by Stratospheric Flight."

Microscopy Exhibition

MESSRS. W. WATSON & SONS, LTD. are holding an exhibition—"The Microscope in Industry and Research"—at the New Horticultural Hall, Westminster on September 15th to 19th, 1952. The exhibition will be open from 2 p.m. to 6 p.m. on the opening day, and from 10 a.m. to 6 p.m. on the remaining days, with the exception that the final closure will be at 4 p.m. on September 19th. An extensive range of microscopes, illustrating the part they play both in industry and research will be displayed. The specimens to be shown on the instruments will all be provided by users of Watson microscopes and will cover a very extensive range.

A small brochure, which will give details of the various techniques to be displayed, is in course of preparation, and a copy will be sent to readers who are interested on application to Messrs. W. Watson & Sons, Ltd., 313, High Holborn, London, W.C.1.

British Cast Iron Research Association Journal

THE pioneer work of the British Cast Iron Research Association in the development of nodular cast irons is well known and a further contribution to the knowledge of the subject takes the form of a paper by Mr. H. Morrogh on "The Harmful Influence of Some Residual Elements in Magnesium-treated Nodular Cast Irons and their Neutralization by Cerium" which appeared in a recent issue of the Association's Journal of Research and Development.

This publication is designed to assist the ironfounding industry in this country and overseas, and it carries reports of completed research investigations carried out by both the Research and Development Departments of the Association, together with papers which are presented at conferences on foundry topics arranged by the Association from time to time. Typical papers which

have appeared recently have dealt with some fundamental and original work on the fluidity of cast iron, methods of improving working conditions in iron-foundries, an investigation of the relationship between the stress/strain properties of moulding sands and expansion scabs on iron castings, and a method for the quantitative spectrographic analysis of slags.

It is perhaps not generally realised that the Journal has, since August, 1949, been available to non-members of the Association at an annual subscription of £3 3s. for the six issues published each year.

New Sales Company for Steel Products

R.T.S.C. Home Sales Ltd.

RICHARD THOMAS & BALDWINS, LTD. and The Steel Company of Wales, Ltd. jointly announce the formation of "R.T.S.C. HOME SALES, LTD." The Registered Office of the Company will be at 47, Park Street, London, W.1.

The Company is being formed for the purpose of effecting and carrying through as principals (not as agents) sales in all parts of the United Kingdom and Northern Ireland, the Channel Islands and the Isle of Man of the flat-rolled steel products manufactured by Richard Thomas & Baldwins, Ltd. and The Steel Company of Wales, Ltd. The capital of the Company to start with will be £10,000, divided into 10,000 shares of £1 each—£5,000 being subscribed by Richard Thomas & Baldwins, Ltd. and £5,000 by The Steel Company of Wales, Ltd.

The first Directors of the Company will be Mr. H. F. Spencer, the Assistant Managing Director of Richard Thomas & Baldwins, Ltd. and Mr. E. Julian Pode, the Managing Director of The Steel Company of Wales, Ltd., who are Directors of R.T.S.C. Exports, Ltd. which was formed a year ago to co-ordinate and stimulate sales of these products throughout the world.

The Company will not become active until near the end of this year or early in 1953 and customers are being requested to continue their present contacts with the individual companies until advised to the contrary.

Exhibition of Scientific Instruments and Laboratory Equipment

MESSRS. STANDLEY BELCHER & MASON, LTD., have arranged a series of Exhibitions at which they will show a representative selection of their latest apparatus of interest to industry, research and education. The dates and locations are as follows :—

CARDIFF : The Royal Hotel—September 30th, October 1st and 2nd.

GLOUCESTER : The Fleece Hotel—October 7th, 8th and 9th.

NOTTINGHAM : The Welbeck Hotel—October 14th, 15th and 16th.

LEICESTER : The George Hotel—October 21st, 22nd and 23rd.

BIRMINGHAM : The Grand Hotel—October 28th, 29th and 30th.

The exhibitions will be open each day from 10 a.m. to 12 noon and from 2 p.m. to 4 p.m., and there will be additional sessions from 6 p.m. to 8 p.m. on Wednesdays, October 1st, 8th, 15th, 22nd and 29th.

Personal News

MR. E. SHAW, Sales Director of the Oughtibridge Silica Firebrick Co., Ltd., and Director of Monolithic Dolomite, Ltd., Steetley, has been elected a member of the Council of the Refractories Association of Great Britain. Mr. Shaw, who is widely known in steelmaking circles and has for many years been specialising in basic refractories, in particular basic hearth monoliths, was a member of the Basic Furnace Linings Committee.

MR. F. GRAUCOB, Managing Director of Nu-Swift, Ltd., has been elected Chairman in place of MR. A. HARLAND who has resigned owing to advancing years. Mr. Harland has accepted the honorary post of President of the Company. MR. E. E. C. CAWOOD, M.B.E., General Manager, has been appointed Technical Director.

MR. P. V. HUNTER, C.B.E. is resigning from the position of Deputy Chairman of British Insulated Callender's Cables, Ltd. at the end of August. He will then be in his seventieth year and is desirous of reducing his commitments. He will, however, continue as a non-executive Director, and at the request of the Company he will remain on the boards of several subsidiary companies where his long experience and technical knowledge are of special value.

THE Research and Development Division of the British Steel Founders' Association announces that MR. T. A. COSH has joined the Division's metallurgical research staff.

MR. L. DE WYNTER has been appointed Manager of the Ipswich Branch of British Insulated Callender's Cables, Ltd., with effect from August 1st, in succession to MR. A. R. DRIESSEN who has been appointed Commercial Manager of the Indian Cable Co., Ltd.

DR. W. I. PUMPHREY, Manager of the Research Department of Murex Welding Processes, Ltd., has been made a Freeman of the City of London and a Liveryman of the Worshipful Company of Blacksmiths.

DR. H. SUTTON, Director, Materials Research and Development (Air), Ministry of Supply, was recently awarded the Silver Medal of the Royal Aeronautical Society, in recognition of his outstanding work over many years on metallurgy in aircraft design.

Obituary

IT is with regret that we record the death, at the age of 57, of Sir William Griffiths, formerly Chairman and Managing Director of the Mond Nickel Company.

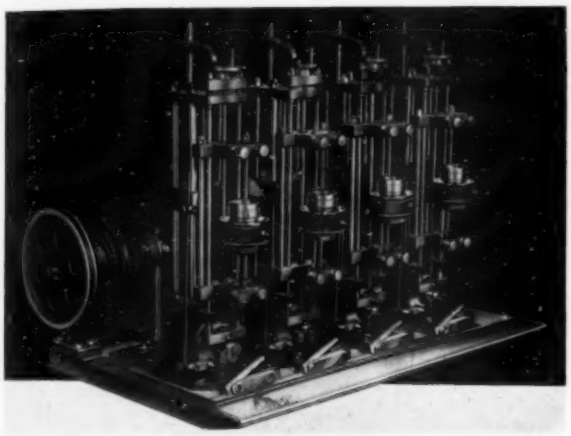
During World War I Sir William served with the Royal Engineers, and subsequently he was appointed a research metallurgist at Woolwich. In 1926 he left Woolwich to take over the position of manager of the research and development department of the Mond Nickel Company. From 1945 until his retirement in 1950 he was chairman and managing director.

Sir William was a member of the Grand Council of the Federation of British Industries and had served on the Councils of the British Cast Iron Research Association, the British Non-Ferrous Metals Research Association, the British Iron and Steel Research Association, and the Iron and Steel Institute. For his paper on high-temperature alloys for gas turbines he was awarded the Simms Gold Medal for 1948 by the Council of the Royal Aeronautical Society.

RECENT DEVELOPMENTS
MATERIALS : PROCESSES : EQUIPMENT

Improved Die-Polishing Machine

IMPROVEMENTS have recently been introduced to their Type 2003/1 B.S.T.E.H. 4-Head Die Polishing Machine by the makers, Rudkin & Riley, Ltd. This machine is designed for polishing and reconditioning diamond dies and small tungsten carbide dies up to 43 mm. case sizes.



The makers claim to be the original designers of a device on this machine which gives an adjustable automatic oscillating movement to the die-holder. By this movement blending of die angles is accomplished in one operation. The amplitude of oscillation is adjusted by finger-tip control, and cam setting from the front of the machine. It should be noted that the oscillating movement may be disconnected if desired; the die-holder can then be locked in a rigid position whereby the bore and angles may be polished by separate settings.

The spindle carrying the die-holder is fitted into two ball races, to ensure a perfectly smooth motion when the oscillating device is in action. Each of the four heads is an independent unit which may be started or stopped separately by means of a clutch arrangement, the whole being mounted on a substantial machined baseplate.

The die-holder, which has a $\frac{3}{4}$ in. diameter hole through the centre, is mounted in a double ball race with grease nipples on the container case for easy lubrication. Special steel retaining caps can be provided to press over the die-holder to accommodate 43 mm. case sizes. Abrasive collecting rings are fitted, thereby saving diamond powder and safeguarding bearings. The machine is also supplied as a double-head.

Rudkin & Riley, Ltd., Aylestone, Leicester.

Aluminium Degreaser and Finisher

THE Orcene Co., Ltd. have developed an alkaline powder, ORPI-50, which, used at the correct concentration, is suitable for degreasing and finishing aluminium articles, the degree of satin or matt finish depending on the temperature and concentration. Apart from the obvious value of its two-in-one process, it is claimed that ORPI-50 shows up to two-thirds saving in working costs as compared with trichlorethylene, etc., and is free from toxic fumes and acidity. The simplicity of the method, permitting the use of unskilled labour, is a further feature.

The powder is mixed with cold water in a soak tank at a concentration of 6–8 oz./gal. and the temperature raised to 100° C. Articles for processing are immersed for 2–3 minutes, removed, and rinsed in cold water. This is followed by a quick dip (10–30 seconds) in concentrated nitric acid, or, in the case of silicon alloys, a 4 : 1 mixture of concentrated nitric and hydrofluoric acids followed by a second rinse in cold water. It is essential that the acid be kept cool (10° C.) and this is easily achieved by running the cold rinsing water through a cooling coil in the acid vat. The degree or depth of satin or matt finish can be controlled by varying slightly the concentration of the powder.

The Orcene Co., Ltd., Victoria Street, Warwick.

Lime Type Stainless Steel Electrodes

IT is now many years since Rockweld stainless steel electrodes were first put on the market. They started as the familiar Chromend series—Chromend C for niobium-bearing steels and Chromend BB for molybdenum-bearing. During the last war, the emphasis shifted from the normal stainless types to the special types required for welding armour plate, but the knowledge and experience gained during this period in perfecting the Armend series of electrodes was invaluable after the war in enabling the Chromend series to be brought up to standard to meet exacting modern requirements. At this time, the range was considerably extended and shortly afterwards given the new generic name "Chromac."

In putting the original Chromend electrodes on the market, Rockweld had to consider very carefully the relative merits of the possible types of coatings that could be used on stainless electrodes. It seemed at the time that what was required was a coating which would give smooth running and easy slag removal in deep v's where high radiographic standards had to be achieved. It also seemed desirable that the electrode should be capable of operating on A.C. using a normal welding transformer. Thus the Chromend, and later the Chromac, series were produced with a lime-titania type of coating. The special type of lime-titania coating developed gave the rods the properties outlined above.

Recent work has shown, however, that although the lime-titania coating represents the best possible compromise for general work, there are applications in which the fully basic or lime type may be an advantage. For instance, where it is not possible for a fabricator to ensure that the electrodes are dry prior to welding, less pin-holing is liable to be encountered with the lime-type than with the lime-titania type. This can occur, say, in site welding, or in damp shops where drying facilities cannot be readily organised. Furthermore, in instances where welding is carried on under heavy restraint, the lime coating will show less tendency to fissures than the

lime-titania one. This applies especially to those electrodes where the deposit analysis is adjusted to give a fully austenitic structure and, in fact, the Chromac TT and X type, which fall into this category, have for some time been produced with a lime coating only.

There appeared to be a case for introducing lime-coated electrodes in parallel with certain of the present lime-titania coated rods. Lime coatings have now been developed for grades corresponding to Chromac C, Chromac MM and Chromac MC. A suffix L is used to indicate a lime type—*e.g.* Chromac LMM. The deposit analyses and mechanical properties are identical in the two series of electrodes.

Thus for the economic production of welds to high radiographic standards, for smoothest running, or for A.C. operation, the lime-titania grade is recommended, whilst for maximum freedom from porosity under damp conditions, and highest resistance to cracking and fissuring, the best electrode is the lime type.

It should be pointed out that the above properties are not exclusive to the respective types. For instance, perfect radiographs can be produced with the lime types but, to do so, rather more care is necessary in removing the slag between runs. It is also possible to run them on A.C. but an open circuit voltage higher than 90 is required for adequate arc stability. Similarly, experience over many years has shown that the lime-titania types will give pore-free welds under all except the very worst conditions, and immunity from cracking unless restraint is unusually severe.

Rockweld, Ltd., Croydon, Surrey.

Glo-Mor Fluorescent Ink

A RECENT development of the Physics Department of Manchester Oil Refinery, Ltd., is a new fluid for use in fluorescent crack detection which is marketed under the name of Glo-Mor Fluorescent Ink. It is used for finding surface cracks, and cracks extending to the surface in non-magnetic materials, although it can equally well be used for the examination of magnetic materials. The action depends on its penetration into cracks of degreased test pieces which are free from mechanical debris, and on depositing a fluorescent material in the cracks. Since the surface tension of the "ink" is the controlling property for its penetration power, any fluorescent "ink" is searching for fine cracks which are visible to the naked eye. It is not designed to show cracks which are easily visible with the naked eye.

The "ink" is applied to the surface of the cleaned, degreased piece, either by dipping in a tank of "ink" or by pouring the "ink" over the test piece, or over that portion of the test piece which requires examination. If the test piece is large, the "ink" may be brushed over the suspected area. A rapid drop into carbon tetrachloride removes the fluorescent material on the surface without washing it all out of the cracks, but speed is essential. When examined under ultra-violet illumination the cracks reveal themselves by their brilliant green fluorescence. A particularly suitable source of ultra-violet light is the Fluorescence Lamp, Model 15, made by Hanovia, Ltd., of Slough. This pistol-grip model is portable, weighing only 2 lb. and, manipulated like a hand torch it gives a powerful beam which, even in semi-daylight, gives brilliant fluorescence effects at distances up to several feet.

The method is suitable for aluminium and magnesium alloys and any other parts which form structural members of aircraft or of internal combustion engines; turbine blades which can be inspected in situ; welded plates and any other welded structures which may have shrinkage cracks or porosity; plastic materials, particularly plastic insulators; the examination of the flatness of surfaces in conjunction with a straight edge; pistons; stainless steel parts; and the detection of cracks and holes in hydraulic systems.

Manchester Oil Refinery, Ltd., Twining Road, Trafford Park, Manchester, 17.

Nimonic 95

IN order to meet the steadily increasing demands of gas turbine engineers for materials which will withstand still higher temperatures and higher stresses than the alloys used in current production engines, the research metallurgists of The Mond Nickel Co., Ltd. have continued their investigations in the field of precipitation hardening nickel-chromium alloys. The latest outcome of these investigations is the alloy Nimonic 95 which has recently been announced. The new alloy is similar to Nimonic 90, but the creep-resistance at elevated temperatures has been improved by increasing the content of the hardening elements.

All alloys which have high creep-resistance at high temperatures are necessarily difficult to hot-work and one of the major problems in the development of a new alloy is to maintain sufficient forgeability to enable the material to be worked to the required form. Any increase in the maximum temperature at which an alloy is serviceable necessarily involves a reduction in the temperature interval within which hot-working must be carried out, for the increase in the amount of alloying elements does not usually produce at the same time an increase in the melting point of the alloy. Nevertheless by careful control of the proportions of the hardening elements and of the methods of melting and casting of ingots, as well as by improvements in the technique of hot-working, it has been found possible with Nimonic 95 to maintain adequate forgeability for practical purposes.

Since Nimonic 95 has only been developed within the last few months it has not yet been possible to determine its creep properties in long-time tests or over a wide range of temperatures, but its properties for the relatively short periods which are of major interest for aircraft jet engines show a considerable improvement over those for Nimonic 90. The properties are summarised in the following table which gives the stress required to produce fracture in 100 hours at temperatures between 750° and 925° C. and the approximate minimum creep rate for tests at that stress.

Temperature °C.	Stress to Rupture in 100 Hours Tons/Sq. In.	Approximate Minimum Creep Rate for 100-hour Test—Percent./Hour
750	22	0·002–0·005
815	14	0·002–0·005
870	9	0·002–0·005
900	6·5	0·005–0·01
925	5·0	0·005–0·01

Tests are in hand to extend the knowledge of the creep resistance of the new alloy and to determine other properties of importance to designers, but in the meantime it is being produced by Henry Wiggin & Co., Ltd. and is being used in experimental quantities by engine builders.

CURRENT LITERATURE

Book Notices

POLARIZED LIGHT IN METALLOGRAPHY

Edited by G. K. T. Conn and F. J. Bradshaw. Prepared for the Optical Methods Sub-Committee of the British Iron and Steel Research Association. 130 pp., 51 illustrations. London, 1952. Butterworth's Scientific Publications in conjunction with B.I.S.R.A. 21s.

In his preface to this book, Dr. Conn, who is Chairman of the Optical Methods Sub-Committee of B.I.S.R.A., suggests that as the microscope is probably the most valuable and most commonly used instrument in a metallurgical laboratory, it is surprising that microscopic studies using polarized light appear to have been relatively neglected. In the spring of 1950, the B.I.S.R.A. Advisory Committee on Optical Methods decided that the matter of microscopic studies using polarized light should be examined, and as an essential preliminary to such an examination an assessment of the present position and of future prospects was made, since no comprehensive survey of the field was then available. In the belief that such an assessment may be of value to a wider public, it has been published in the form of this book.

Chapters 1 and 2, by G. K. T. Conn and J. M. Naish, deal respectively with polarized light and anisotropic materials, and the principles of reflection and absorption, whilst the third introductory chapter, by A. F. Hallimond and E. W. Taylor, describes the equipment and procedure for microscopy by reflected polarized light. Chapter 4 is a critical survey, by E. C. W. Perryman, of work which has been carried out and of the conclusions reached in the study of metals and alloys. The work of Morrogh on the metallography of cast iron is well-known and in Chapter 5 he discusses the important topic of inclusions, for the identification of which polarized light has proved to be of great value. Again, in the study of ores and slags, polarized light can be of considerable assistance, as will be seen from Chapter 6, in which E. Cohen deals with this matter. Finally, in Chapter 7, B. W. Mott gives a survey and assessment of what the technique has achieved and may be expected to achieve in the field of metallurgy. At the risk of some repetition, the chapters have been written so that they can, to a certain extent, be read individually.

This monograph does not claim to be exhaustive, and its sponsors feel that if it stimulates practising metallurgists to apply the techniques of polarized light more extensively, it will have served its purpose. Without doubt, this book will be useful to all who are interested in the use of reflected polarized light, but particularly, of course, to practising metallurgists for whom no such survey has hitherto been available.

CLASSIFICATION OF COPPER AND COPPER ALLOYS

Publication No. 36 of the Copper Development Association Kendals Hall, Radlett, Herts. 5th Edition, revised 1952. pp. 28. No charge.

THE information contained in this publication was first collected during the early part of the war to meet the desire of engineer-users and designers for concise tabulated data of the more common copper-base materials. Since the last edition, published in 1948, the issue of new British Standards has necessitated a revision of the tables to bring them up to date, and the opportunity was taken to revise the whole book, and to include additional copper base alloys.

Roughly half the booklet is taken up with copper (including high conductivity copper alloys) and brass in various forms. The remainder includes details on aluminium bronze, gunmetals, tin bronzes, copper-lead alloys for bearings, copper manganese alloys, silicon bronze, copper nickel alloys, nickel silver, and a range of welding, brazing and silver soldering materials.

STRENGTH TESTS ON DRIVEN LARGE DIAMETER ALUMINIUM RIVETS

By J. C. Bailey and A. W. Brace. Research Report No. 13, published by the Aluminium Development Association, 33, Grosvenor Street, London, W.1. 60 pp., numerous illustrations and tables. 7s. 6d.

THE development of large aluminium alloy rivets ($\frac{1}{2}$ in. diameter and over) and of methods of driving them were reported in A.D.A. Research Report No. 8, which also described suitable shapes for the driven point. The present report describes a further extensive programme of tests subsequently made to determine the strength of single driven rivets, both in shear and in tension, the test joints being prepared under practical conditions in a structural fabricating shop. A considerable proportion of the outcome of this work is contained in three Appendices giving tabulated results of: individual shear tests on riveted specimens, individual tensile tests on riveted specimens, and the results of radiographic, macro and visual examinations of riveted joints, together with hardness measurements on driven rivets.

Conclusions are reached concerning differences in ultimate stress values as between single and double shear; the effect on tensile or shear stress of variations in hole clearance; the effects of hot driving; the effects of driving in different conditions of heat treatment; comparison between squeeze and hammer driving; and the effect of point shape.

PROCEEDINGS OF A CONFERENCE ON HEATING, LIGHTING AND VENTILATION FOR IRON-FOUNDRIES, SEPTEMBER, 1951.—

162 pp., 124 illustrations. Published by the British Cast Iron Research Association, Birmingham, 1952. 18s. net.

Since the war there have been signs of a growing awareness among British foundries of the necessity to improve working conditions, and considerable improvements have in fact been made in certain foundries. The report of the Joint Advisory Committee on Conditions in Ironfoundries, now better known as the Garret Report, published in 1947, gave further impetus to these developments by its recommendations on dust and fume removal, lighting, heating and ventilation.

In July, 1950, on the initiative and with the support of the Joint Iron Council, the B.C.I.R.A. set up a Foundry Atmospheres Committee under the Chairmanship of Mr. Colin Gresty, and this Committee subsequently appointed a small but experienced staff to

collect information, to investigate the nature of the problems involved and to carry out the necessary experimental work.

In order to secure the co-operation of the industry and to interest manufacturers of equipment in the programme to be undertaken, and to spread the knowledge and understanding of the problems involved over a wider field, the Association promoted a conference at Ashorne Hill, Leamington Spa, during 26th–28th September, 1951. A list of the papers presented is given below :—

Improvement of Working Conditions in Foundries : Survey of the Problems Involved. W. B. LAWRIE, H.M. Inspector of Factories (Engineering and Chemical Branch).
Incorporation of Dust Control in Foundry Planning. J. HUNTER, B.C.I.R.A. Operational Research Team.
Electric Lamps. F. JAMIESON, E.L.M.A. Lighting Service Bureau.
Industrial Lighting. F. JAMIESON.
Natural Ventilation. L. G. DAVIES, Colt Ventilation, Ltd.
Ventilation Methods in Swedish Foundries. K. NILSSON, AB Svenska Flaktfabriken, Stockholm.
Fans : Their Characteristics and Factors Governing their Selection. R. H. YOUNG, Lecturer-in-Charge of the Department of Fan Engineering, National College for Heating, Ventilating, Refrigeration and Fan Engineering.
Dust in Foundries. W. B. LAWRIE.
Methods of Dust Suppression and Collection. C. G. MCKEOWN, Controlled Heat and Air, Ltd.
Fume and Dust Extraction at the Knock-out. L. W. BOLTON, Morris Motors, Ltd., Wellingborough.
Heating in Foundries. W. D. Bamford, B.C.I.R.A. Foundry Atmospheres Team.
Core Removal and Cleaning of Castings by the Wet Process : W. RUSSELL, Pneulec, Ltd.
Some Experiences with Cupola Spark and Dust Arresters. W. Y. BUCHANAN, John Lang and Sons, Ltd.

The majority of the papers have appeared in the B.C.I.R.A. Journal of Research and Development, but in accordance with various requests the complete proceedings of the conference have now been issued under one cover.

Trade Publications

In Catalogue No. 16B–S, Griffin & Tatlock, Ltd., Kemble Street, Kingsway, London, W.C.2, give details of recently-developed equipment for use in the modern laboratory, much of which was on show at this year's British Industries Fair. A number of items of interest to workers in the metallurgical field are featured and these include a screw-operated metallurgical mounting press with built-in heating and cooling systems ; the specially prepared Microid polishing aluminas ; the Gale dilatometer ; apparatus for the rapid determination of carbon, nitrogen and sulphur in steel (three separate items) ; a laboratory tube furnace ; gas analysis apparatus ; a range of equipment for the examination of powders ; grinding mills ; and drying ovens ; together with items of general laboratory application.

A RECENT small brochure issued by Birlec, Ltd., describes the heat treatment service which is available for continuous copper brazing and bright annealing at their Heat Treatment Division, 95, Tyburn Road, Erdington, Birmingham, 24. The pamphlet also gives some brief notes on the copper brazing process which Birlec have been largely instrumental in developing in this country. This publication will be of interest to many more than the production and heat treatment engineers for whom it is primarily intended.

THE Quasi-Arc Company, Ltd., have produced a revised edition of their popular Instruction Book for Electric Arc Welders. This 68-page booklet describes the arc welding of mild steel in all positions and the text is well supplemented by numerous photographs and diagrams. Copies can be obtained on application to the Head Office at Bilston, Staffordshire.

A NEW 16-page Brochure T.C.854 describing the Twin-Arc Process has been produced by The Quasi-Arc Co., Ltd., Bilston, Staffs. The Brochure contains a full technical description of the Twin-Arc Plant and TWIN-ARC.R electrodes, together with deposition data and instructions how to weld various types of joint. The special advantages of Twin-Arc—increased speed and ease of welding together with a balanced three-phase load at a high power factor—are illustrated, and a comparison is made between Twin-Arc and single arc methods of welding. A list of typical Twin-Arc applications indicates the wide use of the process in many different branches of engineering.

A REVISED and enlarged edition of a publication entitled " Photocells for Industrial Applications " has recently been issued by the Communications and Industrial Valve Department of Mullard, Ltd., Century House, Shaftesbury Avenue, London, W.C.2. It is intended to serve as a guide to the use of the Mullard range of emission photocells which have been specially developed for industrial applications. It contains notes on the principles of operation of both vacuum and gas-filled cells together with characteristics, data and suggested applications.

ALTHOUGH bell furnaces have been used for such varying processes as stress-relieving, nitriding, malleablising and brazing, it is in the field of annealing, and particularly bright annealing in a protective atmosphere, that this type of installation excels, its use being regarded as standard practice in cases where a semi-continuous operational basis is desired. The latest leaflet issued by G.W.B. Electric Furnaces, Ltd., discusses the feature of that Company's furnaces of this type, and examples are given of installations for bright annealing cupro-nickel, nickel-silver, brass, copper, nickel alloys and silicon steel sheet.

WE have received from High Duty alloys, Ltd., a copy of the latest edition of their Hiduminium Technical Data Book. This is produced in three forms : the first gives details of the range of " Hiduminium " alloys, pre-service treatments and comparative tables of proprietary alloys ; the second version contains the data information only, and is intended primarily for use where light alloys, due to circumstances, are not used extensively ; the third edition comprises the complete set of comparative tables only. It is thought that this is the first occasion that the double spiral binding has been used in this country, and it is also the first time that Celloglos finish has been used for such a publication.

THE use of oxygen in the electric arc steel furnace is a modern but fully proven development, and progress in Britain has been rapid over the last three years as decisive advantages, both technical and economical, are gained by using oxygen, without additional capital outlay. A saving in power and increased output are claimed for plain carbon and high chromium steel manufacture, but there are additional advantages in the case of stainless steels. The subject is dealt with in a leaflet recently issued by The British Oxygen Co., Ltd.

LABORATORY METHODS
MECHANICAL · CHEMICAL · PHYSICAL · METALLOGRAPHIC
INSTRUMENTS AND MATERIALS

AUGUST, 1952 Vol. XLVI, No. 274

Precise Measurement of Fatigue Test Load

By M. H. Roberts, B.Sc.
Brown-Firth Research Laboratories, Sheffield.

The lack of precision of the optical lever method of measuring the alternating tension and compression in push-pull fatigue tests led to the development of an electrical resistance strain gauge method, using a cathode ray oscillograph, with which results reproducible to ± 1% can be obtained. Details of the method are given in this article.

IN the Haigh fatigue testing machine, a cylindrical test piece is subjected to a uniformly distributed longitudinal stress which alternates between tension and compression in a sinusoidal manner. The mean stress is usually zero but a static load can be applied if desired. One end of the test piece is fixed rigidly, while the other end is fixed to a laminated iron armature supported on leaf springs between two electromagnets, sufficient air gap being left between the faces for the armature to vibrate. The electromagnets are energised by a two-phase alternator, so that the flux in one is at a maximum when that in the other is zero. The armature is thus pulled first to one electromagnet, then to the other.

Normal Optical Method

To show how much stress, or rather load, is being applied to the test piece, a secondary coil is wound on one of the electromagnets and the voltage induced in it is applied to a special type of voltmeter, in which the series resistance is replaced by an inductance. Since the induced voltage varies as the rate of change of magnetic flux, it will be proportional to the product of the peak flux and the frequency. However, if the circuit is mainly inductive, the rate of change of current will be proportional to the induced voltage, so that the current will vary as the flux and be independent of frequency. The meter thus gives an indication of the force applied, but to obtain an absolute measurement some method of calibrating it is necessary.

The makers of the machine supply a long phosphor-bronze test piece on which an extensometer is permanently fixed. This takes the form of a mirror attached by leaf springs to one end of the bar and deflected by a thin rod joining it to the other end of the bar. A box containing lamp and ground glass scale completes the equipment. In the static calibration a known load is applied (in a standard tensile testing machine) and the movement of the lamp filament image over the scale gives the conversion factor required. When placed in the Haigh machine and subjected to alternating stress, the rapid extension and contraction of the bar cause the lamp image to be spread out into a band of light on the scale, the extremities of the band representing the peaks of tension and compression.

Sources of Error

This optical lever method is open to a number of criticisms :

(1) The deflection obtained on the scale is very limited, and the image is not sufficiently small, sharp or brilliant to read with a high degree of accuracy, especially in the fatigue machine, where the ends of the band of light are difficult to define.

(2) Any trace of bending, due to the difficulty of ensuring purely axial loading, both in the tensile machine used for static calibration and in the Haigh machine, will cause an error, since the extensometer responds to the strain on one side of the test piece, not the mean strain over the cross-section.

(3) The springs and masses in the extensometer system may cause the response of the mirror to vary with frequency, so that its dynamic sensitivity may differ from the static value, depending on the frequency of resonance and the degree of damping.

Discrepancies of disturbing magnitude between the results obtained with this method and the calibration curve, of stress meter reading v range of load, supplied by the makers of the machine, and the general lack of precision of the method, have emphasized the need for a more sensitive and accurate method.

The Use of Resistance Strain Gauges

The increasing popularity of electrical resistance strain gauges suggested a possible method, and in 1947 suitable apparatus was constructed and gauges were cemented to a specially made test piece. More recently, progressive improvements have been made in the apparatus and method of using it, until it can be considered to have reached an advanced state of sensitivity, accuracy and reliability, giving a notable improvement on previous methods. An accuracy of ±10 lb. in a load of 1,000 lb. is usual, and results can be repeated with variations of only ±5 lb. or less.

The basic principle of the method is to connect the gauges in a Wheatstone bridge circuit and adjust the balancing resistance to give zero output from the bridge (*a*) at the instant of greatest tension, then (*b*)

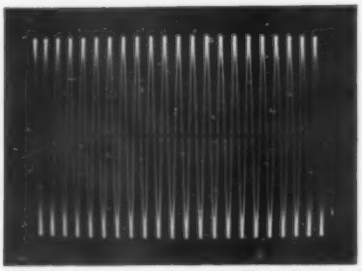


Fig. 1a

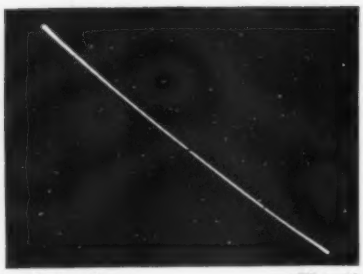


Fig. 1b

Unbalanced by steady tension.

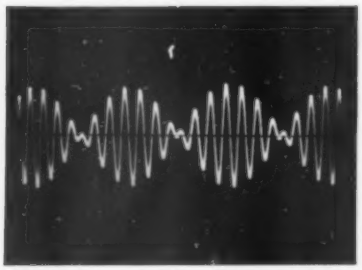


Fig. 2a

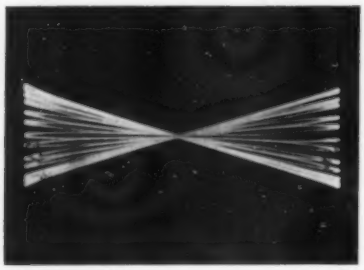


Fig. 2b

Alternate tension and compression.

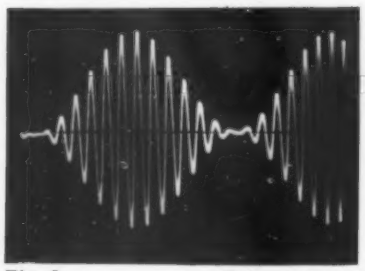


Fig. 3a

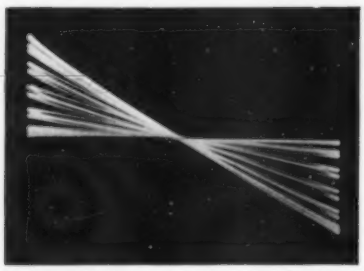


Fig. 3b

Balanced at peak of compression.

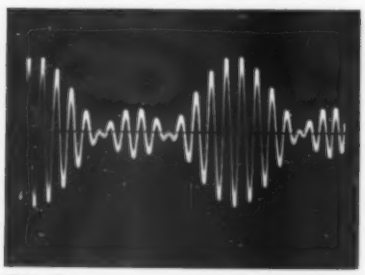


Fig. 4a

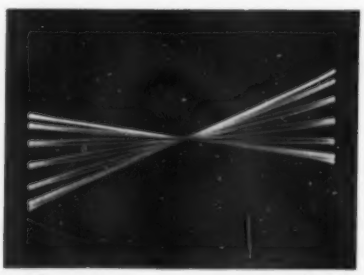


Fig. 4b

Balanced near peak of tension.

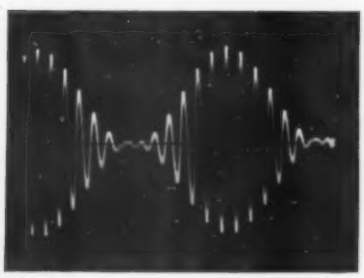


Fig. 5a

Fig. 5b

Balanced at peak of tension

at the instant of greatest compression, during the cycle of vibration. The change in balancing resistance so found is proportional to the range of load between peak tension and peak compression, and the constant of proportionality is found by transferring the test piece to a tensile testing machine, in which a known load is applied and the change of resistance required to restore balance is found. A particularly desirable feature is that it is a null method, requiring no measurement of currents or potentials which may vary. The only variables to be measured are resistances, which can be accurately adjustable and stable.

Bridge Supply and Null Detector. A battery and galvanometer could be used with the bridge circuit for the static calibration, but in the dynamic test the output voltage would be alternating, reproducing the vibration waveform, passing through zero only once or twice in each cycle. These instants could be located with a cathode ray oscilloscope equipped with a direct-coupled amplifier, but such amplifiers have an inherent tendency to drift if the gain is high, so that the zero would be erratic. The use of an amplifier with A.C. couplings, i.e., not responding to a steady voltage at the input, would not show at which instants the bridge output passed through zero, but only the vibration waveform, unaffected by altering the balancing resistance. However, if the battery supplying the bridge could be switched on only for an instant, the pulse of voltage appearing at the bridge output, assuming the bridge to be off balance at that instant, would be passed through the amplifier to the cathode ray tube. A rapid succession of such pulses from the battery would show on the oscilloscope at which instant in the vibration cycle the bridge was in balance.

Use of High Frequency Carrier Wave. This process, in effect, can be realised by applying to the bridge, instead of a battery, an alternating voltage of a frequency much higher than the vibration frequency. The output from the bridge is then an alternating voltage of this high frequency, but varying in amplitude as the balance of the bridge varies, becoming zero only at the instant in the cycle at which the bridge is balanced. The balancing resistance can be adjusted to give zero output at the peak of tension or at the peak of compression. The envelope of the high

frequency carrier wave then represents the waveform of the vibration.

The Oscillograms

The action is best explained by reference to the photographs of the oscilloscope patterns. The output voltage from the bridge is shown as a vertical deflection, so that if the bridge is balanced, with no vibration present, only a horizontal straight line is shown. When the balance is upset by applying a steady tension to the test piece, an output voltage at the carrier frequency is obtained which can be shown either as a waveform, using a linear horizontal time base, as in Fig. 1*a*, or as a Lissajous figure, in this case simply a tilted straight line as in Fig. 1*b*, by obtaining the horizontal deflection from the bridge input voltage. Both types of display are informative and may easily be obtained as desired merely by connecting the *X* amplifier through a changeover switch to either deflection voltage. Figs. 1 to 9 show corresponding patterns, *a* the waveform and *b* the Lissajous figure or "cyclogram," the vertical deflection being the same in *a* and *b* of each pair. To obtain the static calibration, the bridge is rebalanced, to give a horizontal straight line, at various tensile loads, the change in balancing resistance being noted at each load.

When the test piece is transferred to the Haigh machine and an alternating load applied, the horizontal trace corresponding to balance at zero stress changes to the patterns of Figs. 2*a* and 2*b*, showing equal tension and compression loads. In Fig. 2*b*, the line tilts one way for tension and the opposite way for compression whereas Fig. 2*a* does not distinguish between the two. By adjustment of the balancing resistance, one edge of Fig. 2*b* can be made horizontal, as in Fig. 3*b*, showing balance at the peak of compression, the corresponding waveform being as shown in Fig. 3*a*. In practice it is found considerably easier to set the balance precisely with the type *b* pattern, especially when a certain amount of "noise" fluctuation is present on the trace at the highest sensitivity. The edge of the type *b* pattern can be distinguished through the noise, and the slightest tilt is easily detected if the horizontal amplitude is kept small to increase the angle of tilt. With the waveform display it is often difficult to decide exactly when the amplitude drops to zero but does not "cross over."

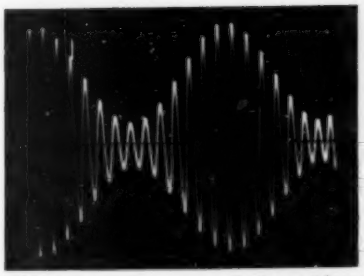
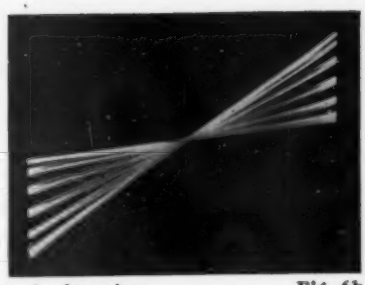


Fig. 6a



Balanced beyond peak of tension — Fig. 6b

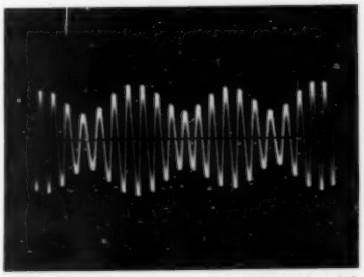
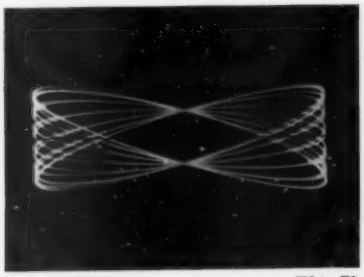


Fig. 7a



As Fig. 2 with reactive unbalance — Fig. 7b

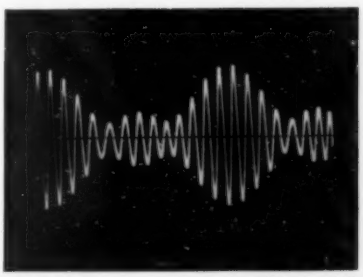
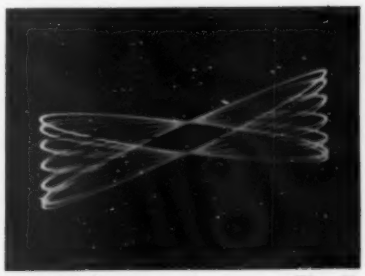


Fig. 8a



As Fig. 4 with reactive unbalance. — Fig. 8b

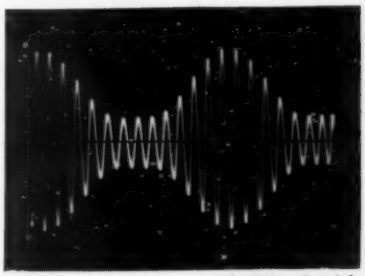


Fig. 9a

As Fig. 5 with reactive unbalance. — Fig. 9b

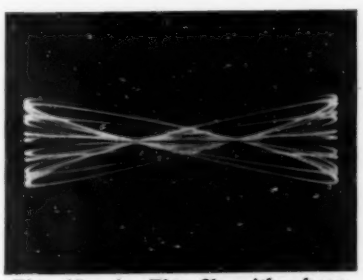


Fig. 10.—As Fig. 2b with phase shift.

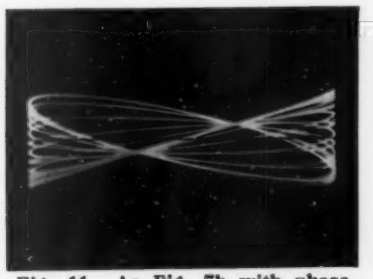


Fig. 11.—As Fig. 7b with phase shift.

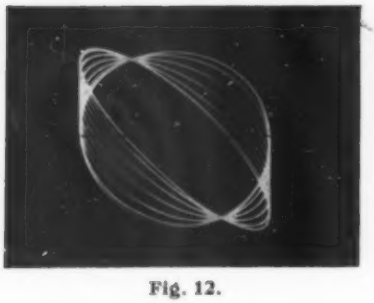


Fig. 12.

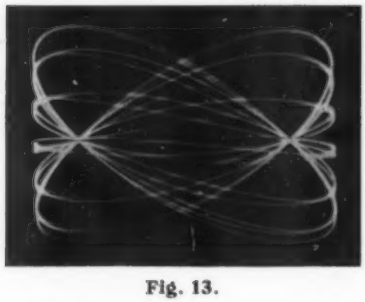


Fig. 13.

Fig. 14.

Fig. 15.

Figs. 12–15.—Effects of reactance, phase shift and carrier frequency variations.

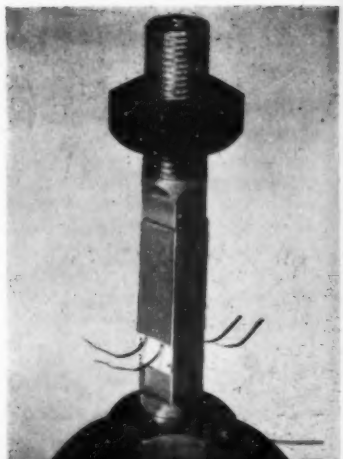


Fig. 16.—Test piece with strain gauges attached.

In order to demonstrate the action more clearly in the photographs, the carrier frequency has been reduced from the normal 2,000 c/s to about 1,300 c/s, and held synchronized at a multiple of the 100 c/s vibration frequency during the $\frac{1}{4}$ sec. exposure, but in actual measurements a 2,000 c/s carrier unsynchronized is preferable, as the pattern then becomes a smooth band of light with distinct edges. The horizontal sweep in the type *a* patterns has been synchronized with the 50 c/s two-phase generator energising the magnets, so that Figs. 3*a* and 5*a* can be distinguished, but without the synchronizing they would appear identical. Fig. 5 shows balance at peak tension, while Figs. 4 and 6 show slightly incorrect settings between which the right value lies. Note that Figs. 3 and 5 are essentially mirror images, though photographed separately at different balance settings.

Another advantage of the *b* display is that lack of balance in the stray reactances is shown as an opening of the line or edge into an ellipse, which is very readily observed and corrected by adjusting a variable capacitor. Figs. 7, 8 and 9 show the effect of unbalanced reactance on patterns 2, 4 and 5, respectively. Such patterns as 7*a*, 8*a* and 9*a* can be rather confusing if their origin is not understood, and it is helpful to switch over to the *b* display. This type of pattern can, however, be unexpectedly complicated if the circuit controls are much out of adjustment, and gives the author a justifiable excuse, if any is needed, for including the fascinating patterns of Figs. 10 to 15. Phase shift in the *X* signal path changes Fig. 2*b* into Fig. 10, and Fig. 7*b* into Fig. 11. Large amounts of unbalanced reactance and phase shift give Figs. 12 and 13, while variations in carrier frequency in addition can lead to an almost unlimited variety of fantastic patterns, of which Figs. 14 and 15 are only two examples. However, provided that the several variables are fairly near their correct values, the adjustment of the bridge by means of the *b* display is simple and straightforward, while the alternative *a* pattern can be used as a check on the actual vibration waveform, which may sometimes show anomalies such as inequality of alternate cycles, due to faulty adjustment of the machine.

Details of Apparatus Used

Strain Gauges. Tinsley type 6K gauges of 100 ohms resistance have been used. Gauges of higher resistance for dynamic work are obtainable but the sensitivity has been adequate with type 6K, which is claimed to have good stability and freedom from hysteresis.

Test Piece. A cylindrical bar of Duralumin, which has a low Young's Modulus, was used in the early experiments, for the sake of high sensitivity, but the gauges frequently failed as a result of the large strains. A report was later seen in the A.S.T.M. Manual of Fatigue Testing that a strain amplitude of only 0·002 would cause fatigue failure of a gauge after a few thousand cycles, so it was decided to reduce the strain to the minimum that could be measured with the required accuracy, after increasing the sensitivity of the electronic circuits as far as practicable.

The balancing resistance used in the bridge circuit was adjustable in steps of 1 in 10^5, so the sensitivity of the amplifier was made adequate to detect this change easily. A change of 1 in 10^3 would then be measurable to ± 1%. With a gauge factor of 2·2, this requires a strain of 0·00045, at a load of 0·75 tons, the maximum instantaneous load applied in the Haigh machine. Using a steel test piece of Young's Modulus about 13,000 tons/sq. in. and cross section area A sq. in., we have $\frac{0{\cdot}75}{13{,}000\ A} = 0{\cdot}00045$, whence $A = 0{\cdot}128$ sq. in. or $(0{\cdot}36)^2$ sq. in.

Thus a steel test piece 0·36 in. square gives the required sensitivity for measurements of load to ± 1% of 0·75 tons, or 17 lb. (Actually, this accuracy was further improved afterwards by a vernier adjustment interpolating between the steps of 1 in 10^5.)

Also, a square cross section gives a flat surface for sticking the gauges, and enables two of them to be positioned symmetrically on opposite sides so that by connecting them in series the mean strain is measured and bending has no effect, while a spare pair of gauges can be mounted on the remaining two sides, for use as a check. Steel has the advantage over Duralumin of a much lower temperature coefficient of Young's Modulus, making the calibration less dependent on ambient temperature. The dynamic stress produced in the test piece by the Haigh machine is well below the fatigue limit, and in the static calibration, to increase the accuracy and check the linearity, much larger loads can be applied without plastic deformation.

The material used for the test piece is a 3% Cr-Mo steel, hardened and tempered to a tensile strength of 58 tons/sq. in. After machining, the test piece is stress relieved for 1 hour at 650° C.

The adaptor used for fixing the lower end of the test piece in the machine also serves to mount the two dummy gauges, which are connected in series to form the temperature compensating arm of the bridge. Fig. 16 shows the test piece and gauges. Durofix thinned with a little amyl acetate is used to stick the gauges on surfaces finished with No. 0 emery, and a simple screw clamp squeezes each pair of gauges towards each other, keeping them flat against the steel until the cement has set. After drying for a week at room temperature, the gauges are covered with Di Jell 171 to keep moisture out.

The Bridge Circuit and its Supplies

Fig. 17 shows the arrangement of active gauges *A*, dummy gauges *D*, fixed resistance *F*, and variable resistance *V*, in the bridge circuit, with input from oscillator and output to cathode ray tube, the amplifiers being omitted for clarity.

In the early experiments, the two gauge arms of the bridge were balanced by two fixed resistors with an "apex" potentiometer between them, but later it was found more convenient to use a pair of decade resistance boxes which were available. One of these, a 5 decade box, provided steps of 0·1 ohm up to 11,111 ohms, the other had no tenths decade, giving 11,110 ohms maximum. With the latter set permanently at 10,550, the 5 dial box was varied to balance the bridge.

Thus the adjustment could be set to 1 part in 10^5, assuming the sensitivity to be high enough to detect such a change. The resistance boxes provided accurately known and stable values of resistance, with no trouble from variable resistance at the contacts, which were of substantial multi-leaf construction. Fixed resistors of suitable value, with a 3 decade box in series with one of them to cover the range of variation required, would of course be equally suitable. The value of 10,550 was chosen for the fixed arm to avoid changing from 9 to 10 on the highest decade, as the actual values may be up to 0·1% different from the nominal values.

The input and output connections of the Wheatstone bridge may be interchanged, as is well known, so the relative merits of the alternative arrangements must be considered. If current flows through gauge arm and

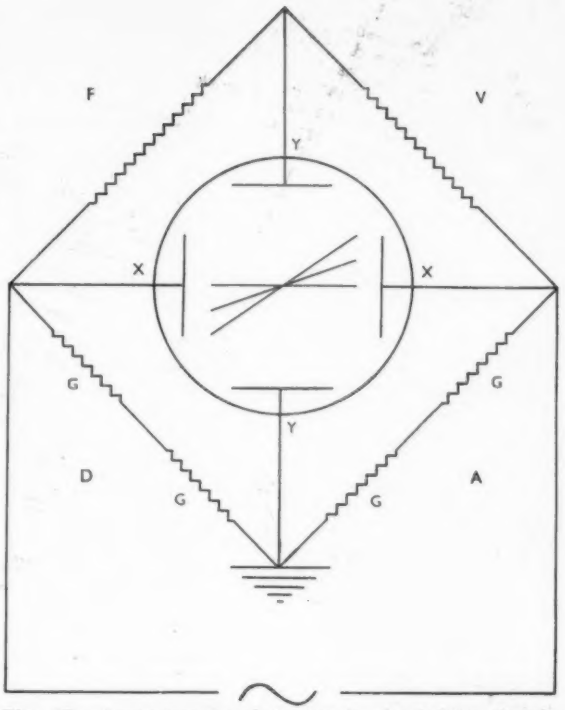


Fig. 17.—Arrangement of gauges in the bridge circuit.

resistance box in series as in Fig. 18*a*, the voltage drop across the 10,000 ohm box will be 50 times that across the two 100 ohm gauges forming one gauge arm. This will require a large input voltage to provide a reasonable gauge current, and if the output circuit is earthed at some point (which is desirable), the bridge is unsymmetrical with respect to earth. The alternative arrangement, Fig. 18*b*, in which the two gauge arms carry the same current in series, while the two boxes carry a much smaller current, gives symmetry and requires less power, and the sensitivity is found to be adequate. The current passed through the gauges is about 25 to 30 mA. The centre tap of the gauge arms can be earthed, greatly reducing danger of picking up interference on the long screened leads from the gauges to the rest of the bridge circuit.

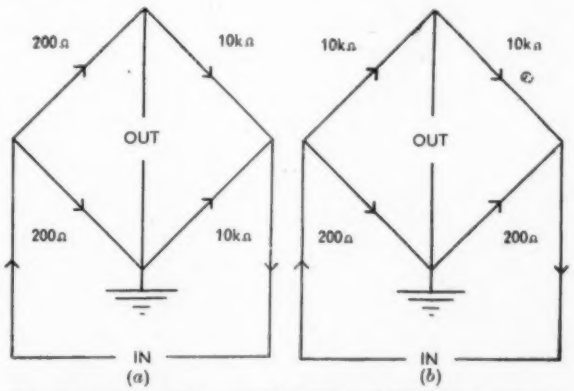


Fig. 18.—Alternative arrangements of input and output connections to Wheatstone bridge.

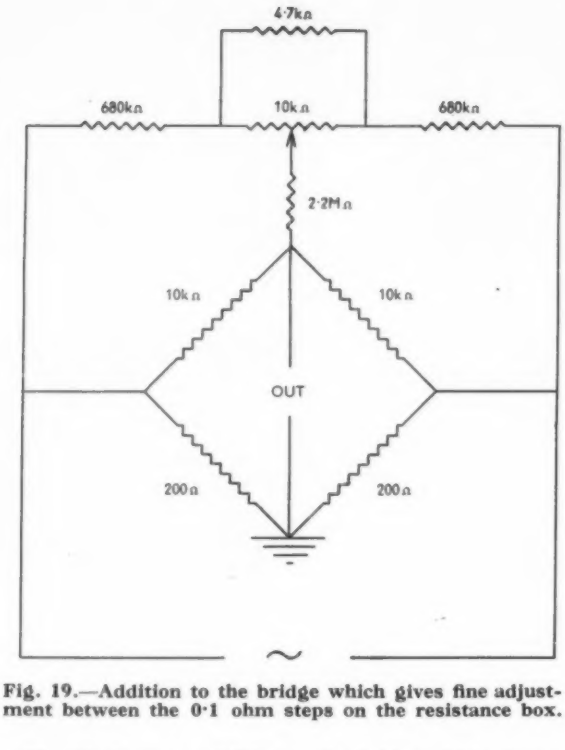


Fig. 19.—Addition to the bridge which gives fine adjustment between the 0·1 ohm steps on the resistance box.

Fig. 19 shows an addition to the bridge which gives a continuous fine adjustment between the 0·1 ohm steps on the resistance box, enabling greater accuracy in setting to be achieved. A rotation of 180° on the 10 kilohms linear potentiometer approximately equals a 0·1 ohm step.

At a frequency of 2 kc/s, sharp balance cannot be obtained without some adjustment to equalise the effect of stray capacitance and inductance in the bridge arms. The wiring is made as symmetrical as possible using equal lengths of screened cable on each side of the bridge, and the metal cases of the resistance boxes are earthed.

The most satisfactory way of providing reactive balance has been found to be the use of a variable capacitor (350 or 500 pF air-spaced) in parallel with one gauge arm and a fixed capacitor, chosen by trial, across the other. It is not the ideal method, as inductance in the boxes is not compensated for at all frequencies, but in practice it does not appear to cause appreciable errors.

Harmonics in the bridge supply must be avoided, as the bridge is unbalanced at their frequency when balanced at the fundamental. They appear as a spiky waveform if the power amplifier supplying the bridge is overloaded. The waveform obtained from the audio oscillator type H1, by Advance Components, Ltd., has been found quite satisfactory. The power amplifier, constructed in our laboratories, uses push-pull triode output (2 KT 61s) with negative feedback from the output anodes to the cathodes of the preceding push-pull stage, leaving the secondary of the output transformer floating, earthed only in the bridge circuit.

An output transformer in which the capacitances between primary and secondary are not symmetrical can give rise to a large reflected capacitance in the bridge circuit, in a manner analogous to the Miller effect in a triode. An electrostatic screen between primary and secondary eliminates this effect, leaving only small inequalities of reactance to be balanced.

A preamplifier is needed to bring the bridge output up to a level high enough for the normal oscillograph amplifier to show ample deflection, the noise level then being visible on the screen. The temptation to reduce noise by sharply tuning the amplifier must be resisted, as that would reduce the amplitude of the sidebands relative to the carrier and thus reduce the depth of modulation giving an incorrect balance. A flat-topped band-pass filter would be permissible, however, but has not been found necessary.

A step-up auto-transformer of 4:1 ratio, well screened with Mumetal, raises the level of the output voltage from the bridge and reduces the effect of valve noise. A low-noise preamplifier (EF 37A) further increases the signal and passes it through a cathode follower (the low output impedance of which prevents interference pick-up on the output lead) to the normal oscillograph Y amplifier. It is very desirable to have an oscillograph amplifier which overloads symmetrically on large signals, so that full sensitivity can be used for bridge balancing even at large stress amplitudes, which send the peaks of the trace right off the screen. The modern push-pull direct-coupled deflection amplifier is greatly superior in this respect to the older style of single-ended amplifier. The overall sensitivity of the oscillograph and amplifiers excluding the step-up input transformer, is about 40μV, R.M.S. per cm.

Fig. 20 shows a block diagram of the whole equipment.

Photographs. The oscillograms were photographed on the 6-in. screen of a VCR 517 working at 2kV, with a Kodak Retina I 35 mm. camera. A 2 dioptre supplementary close-up lens was used to enable the lens to be focused at 33 cm., giving an image about $\frac{1}{8}$ life size, and the exposures were $\frac{1}{4}$ sec. at f/3·5 on FP3, developed for 16 mins. at 65° F. in D23. If adequate exposure is given, high contrast development is unnecessary, and is undesirable as it would merely exaggerate the difference in brilliance in parts of the trace where the spot velocity varies. A black cloth was draped over oscillograph and camera to eliminate stray light and thus obtain a black background.

Procedure for Calibration

The static calibration is carried out on the 2·75-ton range of the Denison tensile testing machine, readings being taken at loads of 1, 1·5, 2, and 2·5 tons. The procedure is to take a reading at zero load, then at 1 ton, then at zero again, and so on, with two readings at each value of load and a zero reading between every two load

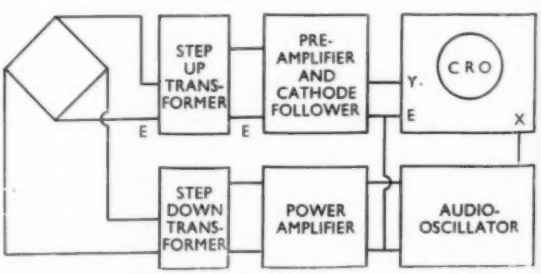


Fig. 20.—Block diagram of whole the equipment.

readings. Then by taking the difference between the load reading and the zero before and after it, any gradual drift is eliminated. The two readings at each value of load expose any lack of reproducibility, and the four values of load allow the linearity of resistance change v load to be checked. From the mean of the two readings at each load a sensitivity factor, change in resistance per unit load, is calculated, and this is plotted against load. Ideally a horizontal straight line results, and a variation greater than $\frac{1}{2}\%$ in the factor throws suspicion on the fixing of the gauges or the elastic properties of the test piece, if no instrumental errors are responsible. The mean sensitivity factor thus obtained is used to convert resistance changes measured in the dynamic test into load values.

In the Haigh machine a suitable reading on the stress meter is obtained and the bridge balanced, as shown in the oscillograms, first at the peak of tension, then at the peak of compression, no zero readings being necessary, though one may be taken to find out whether equal tension and compression loads are being applied. The difference in balancing resistance at the two peaks gives the range of load applied. This is repeated at as many values of load as are needed to fill in the curve over the range required.

Tables I and II show how the readings are set down most conveniently, and the typical results given indicate the degree of precision attained, in spite of zero drift up to

TABLE I.—STATIC CALIBRATION OF STEEL TEST PIECE NO. 3.

Load tons	Resistance Setting	Mean Zero	Resistance Change	Mean of Two	Mean Change per ton
	ohms	ohms	ohms	ohms	ohms
0	60·35				
1·0	74·03	60·37	13·66		
0	60·38			13·66	13·66
1·0	74·05	60·40	13·65		
0	60·42				
1·5	80·91	60·43	20·48		
0	60·44			20·47	13·65
1·5	80·90	60·45	20·45		
0	60·45				
2·0	87·65	60·50	27·15		
0	60·54			27·13	13·57
2·0	87·65	60·54	27·11		
0	60·54				
2·5	94·57	60·59	33·98		
0	60·64			33·98	13·59
2·5	94·64	60·66	33·98		
0	60·67				

Total for 7 tons = 95·24 ohms.
Mean for 1 ton = 13·61 ohms.
Largest variation from mean = 0·05 ohms. = 0·36%
Sensitivity factor = 13·61 ohms per ton or 164·6 lb. per ohm.

TABLE II.—DYNAMIC CALIBRATION ON HAIGH MACHINE NO. 68.

Stress Meter	Resistance Settings		Resistance Change	Range of Load
	Peak Tension	Peak Compression		
	ohms	ohms	ohms	lb.
0	57·02	57·02	0	0
20	57·77	56·19	1·58	260
40	58·66	55·26	3·40	560
80	59·38	54·35	5·03	828
90	59·82	53·85	5·97	983
100	60·38	53·23	7·15	1178
110	61·02	52·54	8·48	1396
120	61·84	51·61	10·23	1685
	Test repeated to check reproducibility.			
0	56·91	56·91	0	0
30	57·67	56·06	1·61	265
60	58·55	55·12	3·43	565
80	59·33	54·30	5·03	828
90	59·78	53·80	5·98	985
100	60·33	53·19	7·14	1176
110	60·96	52·50	8·46	1392
120	61·83	51·61	10·22	1683
0	56·87	56·87	0	0

Largest variation between pairs = 5 lb.

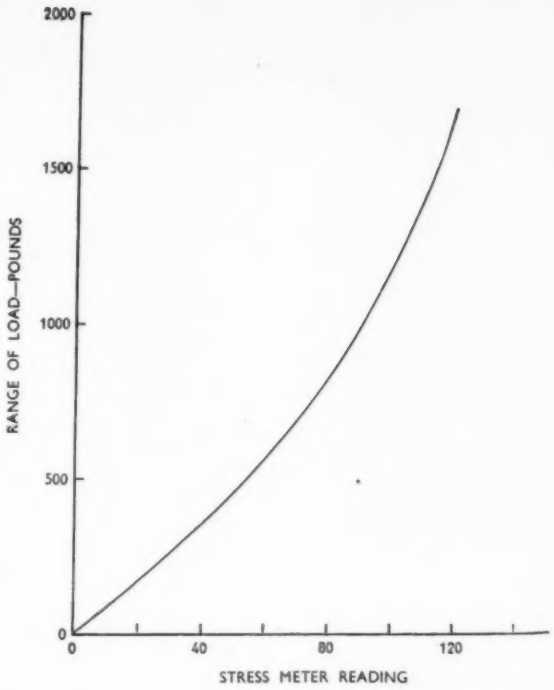


Fig. 21.—Dynamic calibration curve obtained on Haigh machine.

3 parts in 10^5, due to temperature variation in the resistances. The constant 10,500 ohms of the highest two decades are omitted from the resistance settings in the tables. To give more weight to the static readings at high loads, the mean is taken by adding the four quantities in the fifth column, representing the change in resistance for a total load of 7 tons, then dividing by 7. The figures in the sixth column show any departure from linearity.

Fig. 21 shows the curve obtained from Table II, and it will be noticed that the gradient becomes very steep at the top end, so that a slight change in stress meter reading gives a large change in stress. This is due to the close approach of the armature to the electromagnet faces, and at greater amplitudes the faces may touch, causing severe chattering. For these two reasons, therefore, although the machine is rated at a maximum load of 1·5 tons at about 150 on the stress meter, it is considered preferable to regard 120 on the stress meter, corresponding to 0·75 ton, as the maximum usable, and to choose thicknesses of test piece to give the required testing stress at this load or less.

An interesting result obtained in calibrating three machines by this method was that all three curves were identical within 1%, whereas the curves supplied, obtained by the optical method, differed by as much as 8% between one and another. At nearly every point the load as measured by the strain gauge method was lower than the figure given by the optical method, by amounts varying from 20 to 165 lb.

It will be appreciated that the inherent advantage of the method is that it depends only on the accuracy of the tensile machine used for static calibration, the linearity

and constancy of test piece and strain gauge response, and a linear relation between gauge resistance and bridge balancing resistance. No measurements of test piece dimensions, gauge factor, absolute resistance, voltage, current, frequency, or amplifier gain are involved. With sufficient sensitivity in the balance detector, and fine adjustment of the bridge resistance, a very high degree of precision can be attained.

Acknowledgments

The author would like to thank Dr. C. Sykes, F.R.S., Managing Director of Thos. Firth & John Brown, Ltd., for permission to publish this paper.

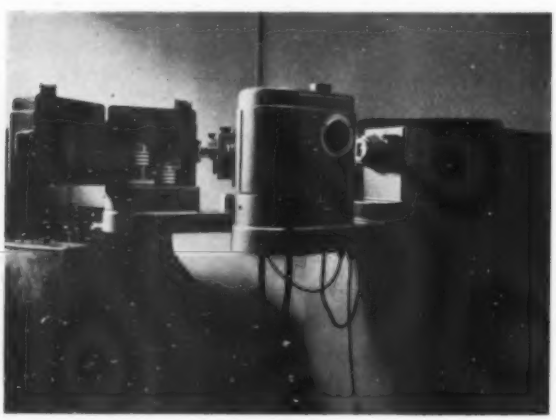
American Scientific Equipment Supplied to British Laboratories

SINCE 1949, over $1,000,000 (£350,000) of American funds have been authorised through E.C.A. (now (M.S.A.) to supply American scientific and research equipment to British research laboratories working to develop better and cheaper industrial and consumer goods and to find new uses for waste products. The equipment, much of it obtainable only in the United States, ranges from special radio valves to such items as the multi-channel direct-reading spectrograph, which are made only in the U.S. Because of the highly specialised nature of much of this equipment, it will be some time before it is all delivered, but about three-quarters of it has already been received.

Compiling the list of equipment required, and screening requests from research organisations representing every major industry, was carried out by the Department of Scientific and Industrial Research. Apart from D.S.I.R. itself, equipment has been going to laboratories working in such diverse fields as coal, iron, steel, textiles, food, chemicals, printing and packaging, shoemaking and even hat-making. In all, 24 U.K. research bodies, other than D.S.I.R. have received, or are scheduled to receive, instruments. In the following notes details are given of a number of items of equipment suitable for metallurgical and allied work.

Analytical Equipment

Both the British Cast Iron Research Association and the British Non-Ferrous Metals Research Association have received multi-channel direct-reading spectrographs, of which it has been said that in scope, speed and accuracy, such equipment allows methods to be used that represent a major advance on any existing rapid analytical technique. This multi-channel equipment is manufactured only in the U.S.



The B.N.F.M.R.A. grating spectrograph.

Originally devised for steel and aluminium alloys, it is now being employed by a number of American firms and also some in this country. The B.N.F.M.R.A. equipment incorporates certain modifications to its own design, and includes a quantometer, a 1½ metre grating spectrograph with recording console and an auxiliary grating spectrograph (Applied Research Laboratories, Glendale, California). The quantometer is being used for the development of spectrographic methods of analysis for copper and complex copper alloys—an investigation which has not been carried out before as a continuous piece of research. The programme includes determination of impurities in unalloyed copper; determination of impurities and major and minor constituents in brasses; determination of minor constituents in gun metal, as typical of the more complex alloys—a research which has given difficulties in the past four years; and a comparison of the direct reading method with photographic methods. The rapidity which the equipment allows means that work which would otherwise have taken two to three years will now be completed in much less time. Elements covered by the quantometer include zinc, tin, lead, aluminium, iron, nickel, manganese, arsenic, silicon, chromium, cadmium, phosphorous, antimony.

The grating spectrograph, with camera, has facilities for a direct reading attachment: when developed, it will use the recording console of the quantometer. A feature is that it has two excitation stands and can thus obtain 1st and 2nd order spectra in the same position. It will be used, amongst other purposes, to develop methods of analysing copper for its selenium and tellurium content—elements not covered by the quantometer. This research is of importance in connection with copper produced in Africa, which contains these elements.

In general, this type of direct recording equipment uses multiplier photo-cells to measure the quantity of light emitted in different wavelengths in the spectrum, pre-selected in accordance with the requirements of the analysis. As indicated above, an extremely wide range of elements can be determined in different alloys and the method is particularly suitable for elements present in amounts around 5% and higher. It has been said that for some analyses the accuracy of the direct-recording method is almost twice as good as with photographic methods. In addition, the complete

analysis for several elements can be made in much shorter time—two or three minutes from receipt of the sample. Such methods may have an important effect in reducing manpower and improving quality control.

The B.C.I.R.A. will use its equipment, amongst other purposes, for investigations into the field of nodular graphite irons which it evolved and which depend upon very small additions of rare elements such as cerium. These irons provide the engineer with a material which may enable malleable cast irons and even cast steels to be replaced in certain instances, leaving these materials for other purposes. It is also expected to enable much more use to be made of cast iron in structures, particularly power units such as automobile and diesel engines, crank-shafts, brakedrums, etc., and to trim the design by taking advantage of the considerably higher strength of this new material.

A unit with special qualities allocated to the Chemical Research Laboratory is a low-voltage multi-source unit (Applied Research Laboratories, Glendale, California). The spectral sensitivities of different elements vary according to the nature of the method of excitation, some exhibiting their greatest sensitivities under arc-like and others under spark-like conditions. This unit, by providing a rapid and flexible change from one extreme to the other, has enabled the laboratory to establish rapidly the most favourable type of discharge for a given analytical problem and to select for analysis those lines giving the greatest reproducibility. Furthermore, the maximum power obtainable by its use is much greater than that of any unit available commercially in Britain, thus considerably increasing the sensitivity of the analyses carried out with its aid.

A Photo-Nephelometer (Colemen Instruments Inc., Maywood, Ill.) is used for the quantitative determination of the turbidity of solutions, and is proving particularly valuable for the determination of trace quantities of metal compounds arising from analytical work, with particular application to minerals and ores. The estimation of trace quantities of thorium as iodate is one example of the use to which the apparatus has already been applied, but many other determinations are being developed. Once again, no equivalent instrument was obtainable.

Mechanical Testing

Testing machines scheduled for the Mechanical Engineering Research Organisation include a Sonntag 10,000 in. lb. rotating bending fatigue machine, and a 40,000 lb. Baldwin-Southwark universal testing machine fitted with automatic strain recorder (Baldwin Locomotive Works, Philadelphia). The former machine will be employed for work on the strength of materials under sustained stress, and the latter will enable extension of the work being done at present on the strength of materials and components used in mechanical engineering. In addition to providing greater stresses than are available with existing equipment, this machine will enable investigations to be made on the effect of size on the strength of materials.

In common with the Production Engineering Research Association, the British Welding Research Association has received a Model F.B. Tukon Tester and accessories (Wilson Mechanical Instrument Co., Inc., New York). This test equipment is fully automatic for determination of Knoop Hardness Numbers and 136 degree diamond pyramid hardness numbers under testing loads of from 25 to 3,600 grams. It will be used for specialised research on the welding characteristics of high tensile steel. The aim of the research is to use higher tensile materials for constructional purposes of all kinds, e.g., buildings, bridges, shipbuilding, etc. If successful, this will result in less weight of steel being required to give the same structural strength and in the development of quicker constructional methods. This in turn would mean a saving of labour and the release of more steel.

The Tukon micro-hardness tester.

Diamond cone indenters supplied to the National Physical Laboratory will enable the laboratory to carry out standard hardness tests using American equipment so that comparison can be made between American and British standards. In this way it will be possible to take full advantage of work that has been carried out in the U.S. on hardness testing.

Also at the N.P.L. " Fosterite " photoelastic material (Westinghouse Electric Corp., Ltd., Research Laboratories, East Pittsburgh, Pennsylvania) is enabling important work to be carried out in the field of photoelasticity by the " frozen stress " method. This method is still comparatively new, but it promises to provide a simple method of estimating stresses, and is, therefore, of considerable significance in the mechanical engineering industry for the design of machine parts.

The Motor Industry Research Association will receive a Stresscoat Outfit from the Magnaflux Corpn., for stress analysis of crankshafts. This is part of the Association's research into the bending and torsional fatigue strength of cast crankshafts. The aim is to determine whether high duty cast irons can be substituted for forged steel, which involves additional processes and is consequently much more costly in man-hours. It will also be employed for work on stress distribution in public vehicle wheels and other components.

Miscellaneous

Another unique instrument received by the B.C.I.R.A. is a high temperature Dilatometer (Harry W. Dietart Co., Detroit), for research into moulding sands. Briefly,

the instrument will be employed to study the basic rheological properties of moulding materials at room and elevated temperatures, the latter being the more important. It is hoped that this apparatus will help to solve the problem generally known as "scabbing," which is caused by the penetration by the molten metal of the mould face. Many castings are scrapped due to this effect. It is also hoped that the work will lead to improvements in the surface finish of castings. The results of this research are expected to increase productivity by reducing the amount of scrap and by enabling castings to be made to closer dimensional tolerances, thus reducing the amount of machining required.

The determination of the moisture content of coal samples will be greatly simplified at the Fuel Research Station by a Brabender semi-automatic moisture tester (Brabender Corp., Rocheli Park, New Jersey) which can finish a complete test in the time it took to weigh a sample by previous methods. The instrument, of which there is no equivalent in this country, takes 10 specimens at a time and dries off the moisture so rapidly that it is completed before oxidation takes place—a snag in previous methods. It is expected that, now the laboratory is in possession of this instrument, the operating time will be much reduced and the solution of existing problems of moisture in coal will be assisted materially.

The Sperry Reflectoscope in operation

Finally, mention may be made of the Sperry Reflectoscope (Sperry Gyroscope Co., Inc., Great Neck, New York) which is being used at the N.P.L. in an investigation of non-destructive testing methods, and of the supply of titanium to the Metallurgy Division of the N.P.L. for further investigations into industrial applications.

New and Revised British Standards

REPORTS ON METRIC UNITS OF VOLUME AND STANDARD TEMPERATURE FOR VOLUMETRIC GLASSWARE (B.S.501/554 : 1952) PRICE 2s. 6d.

B.S.501, "Report on metric units of volume," was published in 1933, and summarised the history of the metric units of volume and the reasons for adopting the millilitre as the metric unit to be used in the chemical industry. B.S.554, "Report on standard temperature of volumetric glassware," was published in 1934, and outlined the case for adopting 20° C. as the standard temperature.

These recommendations have since been widely accepted, both in this country and abroad. All British Standard volumetric glassware is now graduated in millilitres at 20° C. It has not, therefore, been considered necessary to revise the Reports, but in order that the information relevant to these fundamental decisions may continue to be generally available, they have been reprinted verbatim in a single volume.

Addenda have been included recommending the micro-litre as the unit for measuring very small volumes, and setting out revised temperature corrections for both soda and borosilicate glass, related to the coefficients of cubical expansion which are representative of the bulk of current British manufacture of volumetric glassware.

DENSITY BOTTLES. (B.S.733 : 1952) PRICE 3s.

B.S.733, "Density bottles" was first published in 1937, and has now been revised to overcome the difficulties encountered in manufacturing bottles to the original specification.

A new design for the stopper has been accepted, as an optional alternative, which combines a capillary of suitable bore with a wider neck more convenient for the larger sizes of bottle. This makes it easier to fill the bottle with a viscous liquid and to stir the contents thoroughly.

The second major amendment concerns the tolerances on capacity. A density bottle of standard quality is normally used only for work of considerable accuracy, in which the actual capacity of the bottle is required to be known. When using bottles made to the original British Standard, even with the close tolerances specified therein, it was not always possible to ignore the difference between the nominal capacity and the actual capacity, and the latter had, therefore, to be determined by the user. In addition, a density bottle may be used for specific gravity determinations, in which the actual capacity of the bottle is not required to be known, and users then prefer to make their own determination of the weight of water contained by the bottle. The very costly process of adjustment to the original close tolerances is therefore considered not to be justified, and the present edition permits a considerably larger tolerance on capacity.

Apart from the above changes, only minor amendments have been made in the standard, which specifies the material, construction, dimensions and tolerances for 10-, 25-, 50- and 100-ml. bottles. Appendices give, with examples, standard methods of determining density by the use of these bottles, and the calculations necessary in the measurement of liquid in bulk.

Copies of these standards may be obtained from the British Standards Institution, Sales Branch, 24, Victoria Street, London, S.W.1.

Correction

THE PHOTOMETRIC DETERMINATION OF ARSENIC AND ANTIMONY IN TIN

WE regret that an error occurred on the last page of the above article, page 54 of the July issue. The line at the head of the second column—"the distillate with nitric acid are also given. In this case"—should have headed the first column.

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